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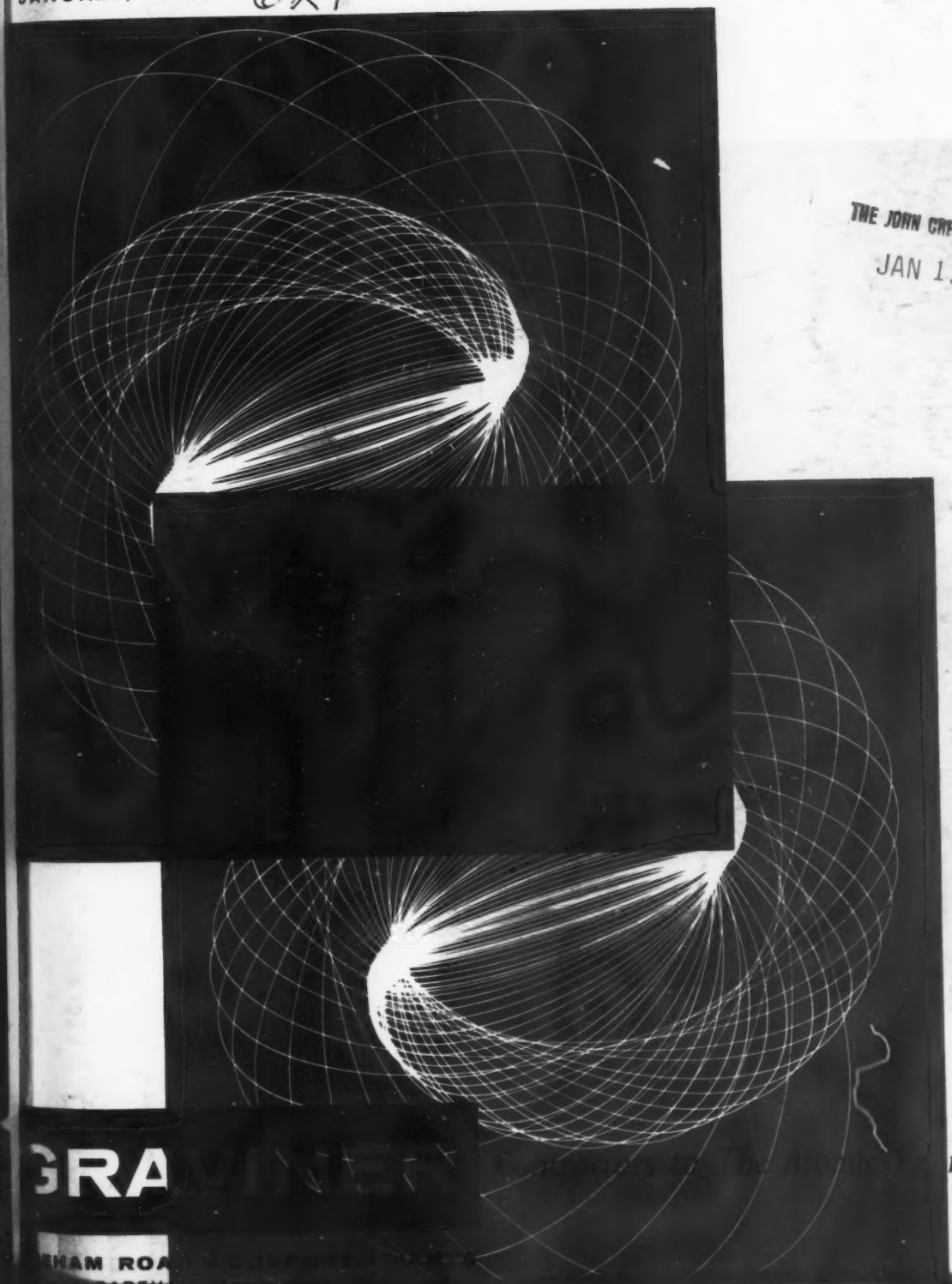

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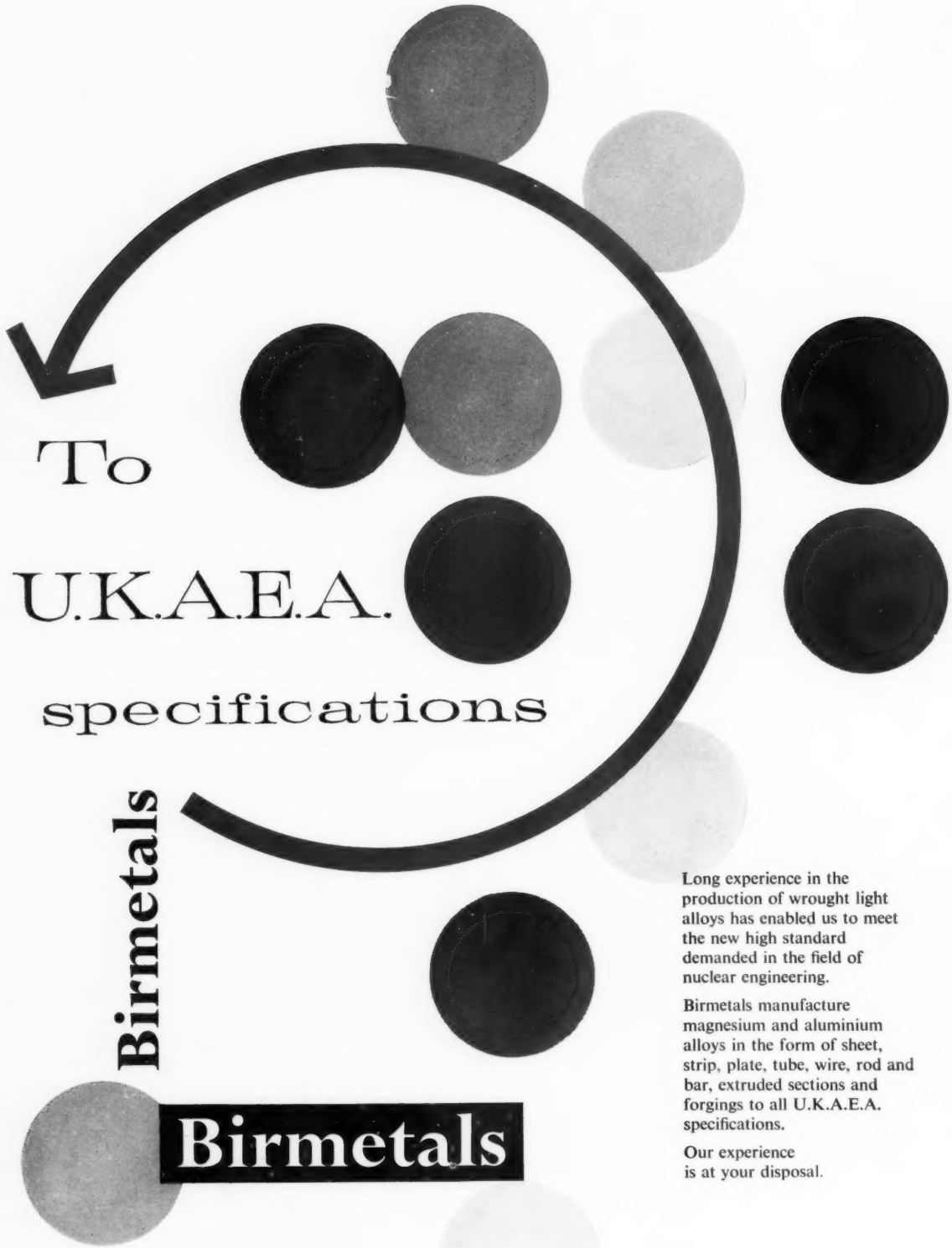

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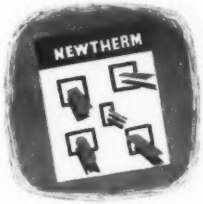

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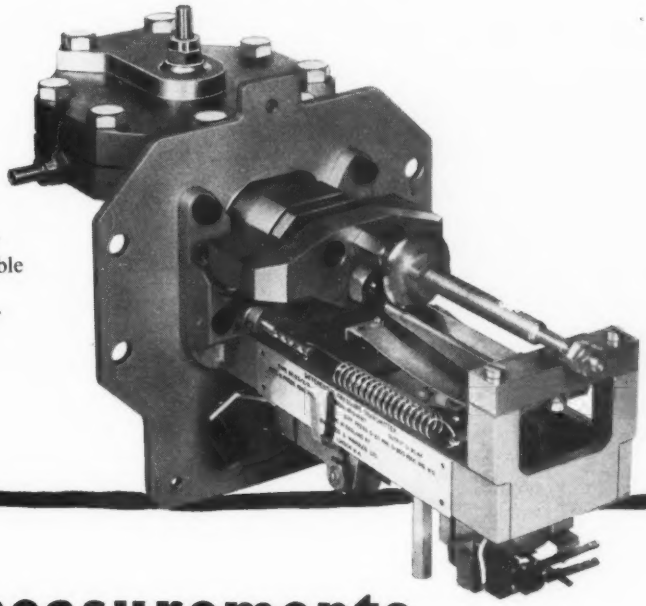

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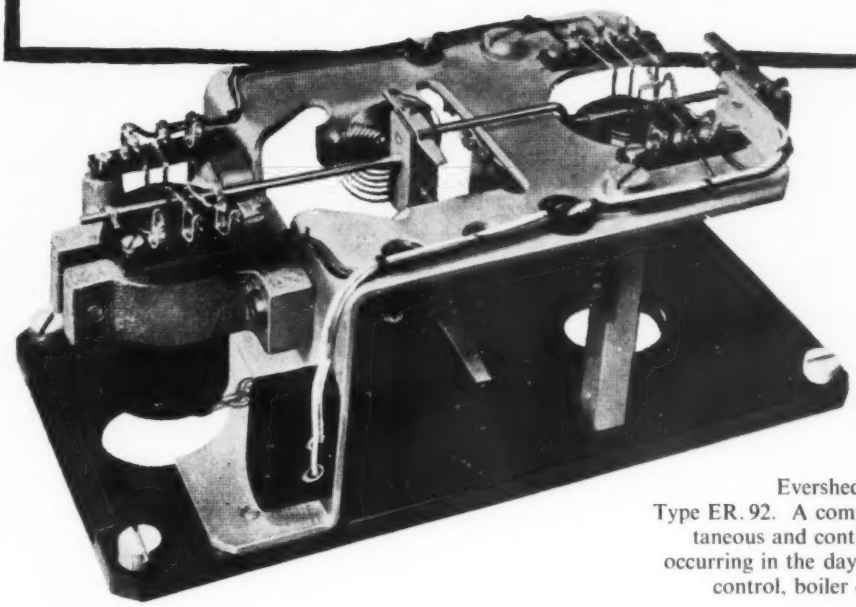

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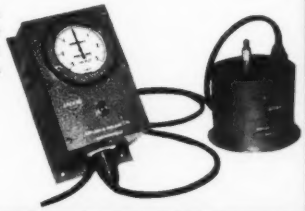

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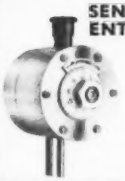

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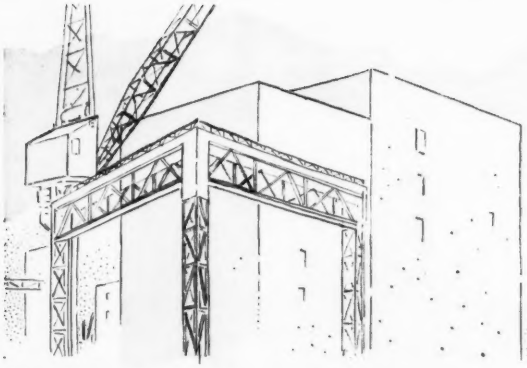

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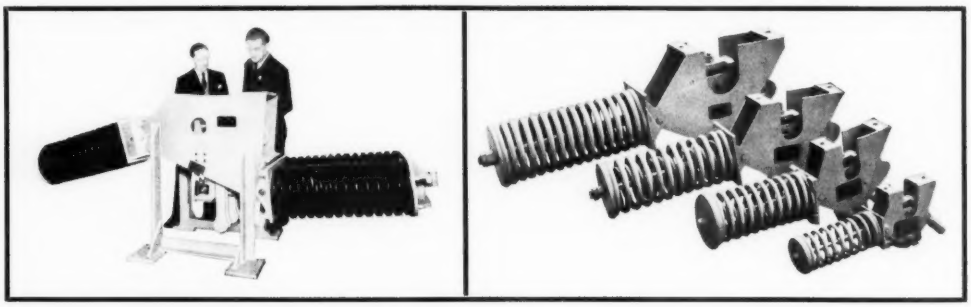

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Vol. 14 No. 140

JANUARY, 1960

CONTENTS

PAGE

Advanced Water Reactor Systems—Three Designs by Westinghouse 11

Neutron Project, Harwell 14

Design of Large Gas Ducts, by A. T. Bowden, BSc, and J. C. Drumm, BE 22

Reactor Simulator—Vickers Mark I and Core Model 26

Isotopes in Holland, by F. R. Paulsen, BSc, PhD 27

Institution of Nuclear Engineers—Members and Associate Members 31

Training N-Scientists in Australia, by L. C. Woods 36

People in the N-News 39

Nuclearist Writes 40

Nuclear News 41

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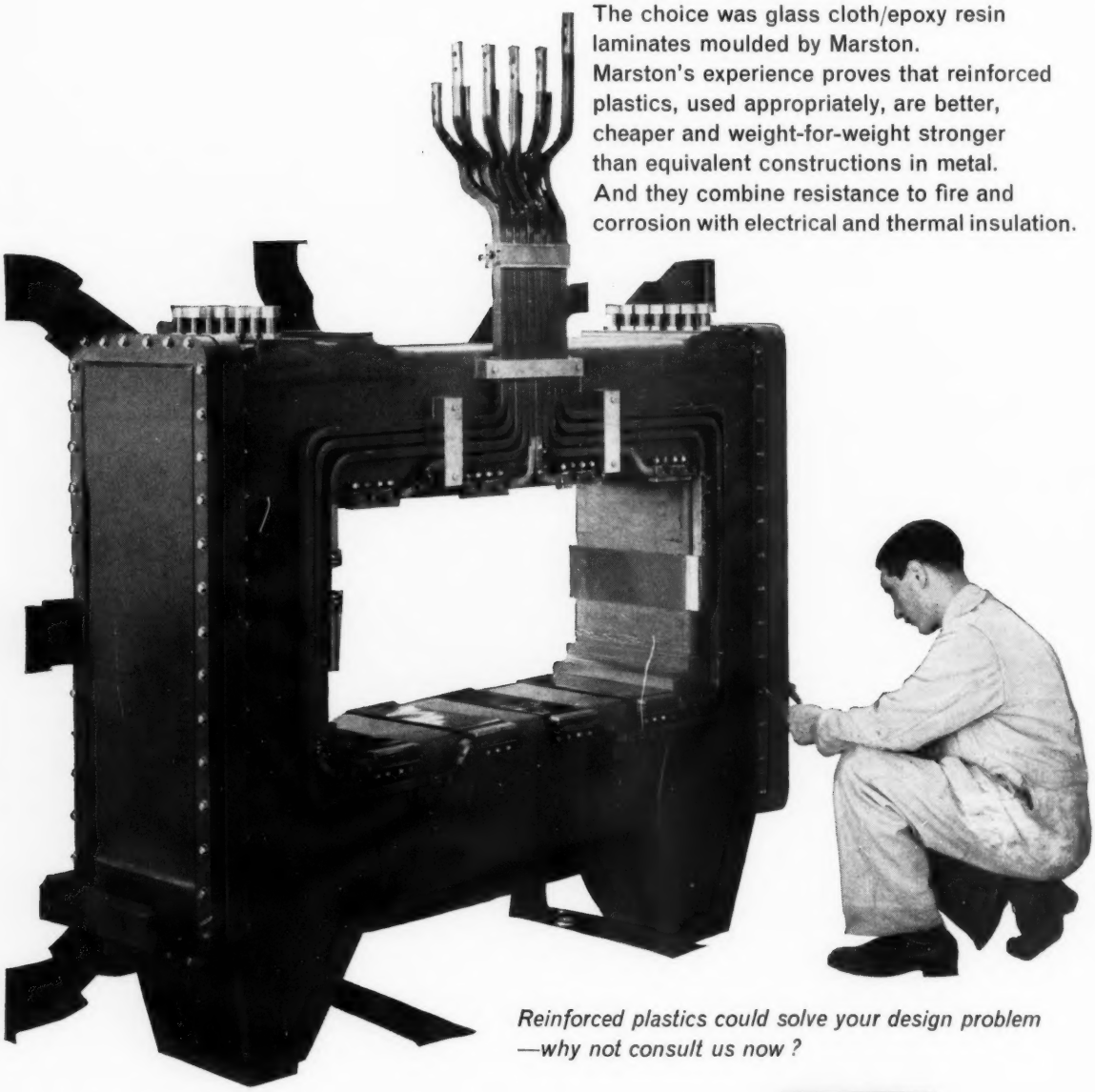

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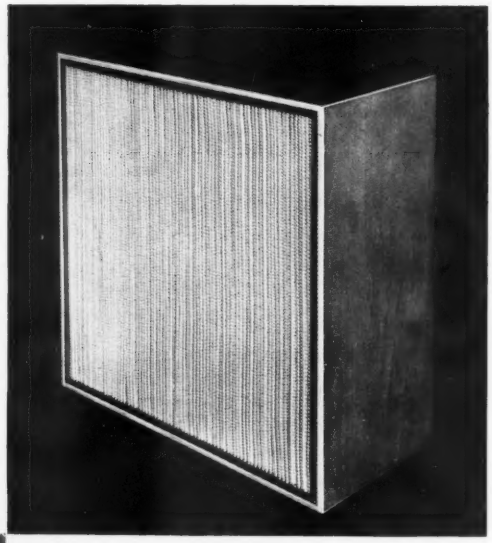

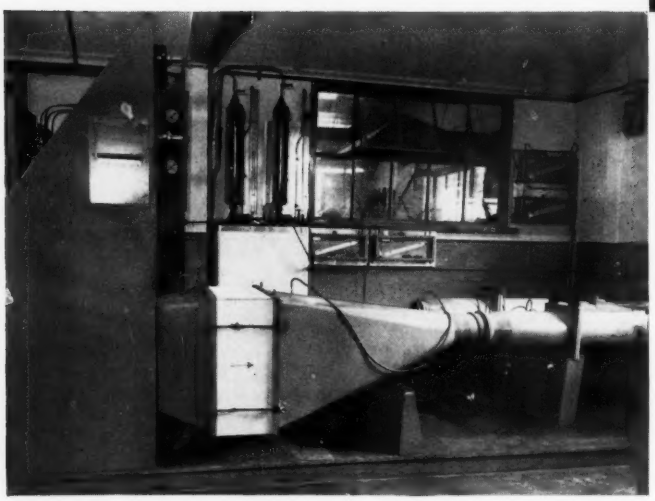

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ADVANCED WATER REACTOR SYSTEMS

THREE DESIGNS BY WESTINGHOUSE

ENGINEERS of Westinghouse Electric Corporation, Pittsburgh, have recently completed design studies of three new advanced water reactor systems for power production. Two of the systems could be applied to large-scale economic stations almost immediately, or, at least, in the very near future, and appropriate working data has been worked out for them. The third system would have to be tried out in a prototype plant before any full-scale plant could be planned; its exponents, however, believe it will prove to be the most practical reactor system in the power industry during the next half-century.

Westinghouse have considerable experience in the field of water reactors, being responsible for the design and development of the pressurized water reactor system used in the Shippingport experimental power station and various U.S. Navy submarines. They have also designed and built the reactor for the recently completed 134 MW(e) Yankee power station at Rowe, Massachusetts. Overseas, the company have been responsible for the 11.5 MW(e) PWR at Mol, Belgium, and they have the SELNI contract for a 160 MW(e) PWR plant in Italy.

Types Investigated

Of the basic water reactor systems already investigated and found practical, several variations are available. The first of these is the closed cycle or pressurized water reactor. In this system, water under pressure circulates through a primary loop, picking up heat in the reactor and giving it up in a heat exchanger to a secondary system that generates steam. This system has a wide range of application—from 1 MW to 400 MW. It is the easiest type to control and the most stable that can be built.

The second major division of the natural water systems is the direct cycle type, where steam from the reactor is piped directly to the turbine. In one such reactor, called the direct cycle natural circulation system, the incoming water passes through the reactor core forming a steam-water emulsion. Steam-water separation is accomplished inside the reactor; steam goes on to the turbine, is condensed, and re-enters the reactor. The difference in density between the steam column in the core and the water column outside is sufficient to cause natural circulation in the steam-water loop. This system has excellent application in the small power ranges from 5 MW to 50 MW. However, because of water flow characteristics and steam separation problems, it takes a very large core to produce sufficient heat.

Improving Efficiency

To overcome this difficulty, forced circulation of the water can be introduced. This brings about higher nuclear efficiency and increases the hydraulic stability of the reactor. Capital costs are increased, of course, but the range of this system is pushed up to about 150 MW. In this size plant, the forced circulation system has excellent prospects.

The combination of the direct cycle and closed cycle system is known as the dual cycle. In one leg of the system which is operated as a direct cycle loop, steam is carried directly from the top of the reactor to the turbine and then back to the reactor after it condenses. Meanwhile, a second leg is operating on the closed cycle basis with heat from the reactor being transferred first to a heat exchanger which generates steam for the turbine.

In the direct cycle end of this system the steam and water are separated outside the reactor; this steam goes to the high pressure end of the turbine. The lower pressure steam from the closed cycle end enters the turbine in its low pressure range. The power range of the dual cycle plant is from 150 MW to 300 or 400 MW. This system has higher power density than the other two but also higher capital costs. There is also the problem of possible contamination of the entire primary system including the turbine generator unit. Since it requires a complicated turbine and control system, this system increases in cost to the point where there is little difference between it and a straight closed cycle plant.

For the larger plants it is important to determine which of these two systems has the greater present and long-range potential. To establish this comparison a number of parallel technical and economic studies have been made for closed cycle and dual cycle plants up to 300 MW. The power costs for the closed cycle and dual cycle plants are essentially identical over the range of applicability. The saving in heat exchanger capacity for the dual cycle plant is almost offset by the reduction in piping and other components for the closed cycle plant.

Where economics are comparable, the choice clearly goes to the closed cycle system. This is dictated by advantages in the important areas of operation and maintenance.

Superheating Next Stage

One of the most effective ways of improving the efficiency of the water reactor type and so reducing the mills/kWh cost is to superheat the steam as it comes from the reactor to bring it up to modern steam turbine conditions. Superheating is then, a significant part of the several specific recommendations included in the three new systems developed by Westinghouse.

The first of these systems is called the Combination Plant—because it uses both nuclear and fossil fuel. It was designed around a modern, currently available turbine and the steam conditions it requires. The

nuclear reactor and superheat-reheat system was then designed to meet these conditions.

The turbine, rated at 225 gross MW, can essentially be ordered from the catalogues. Steam inlet conditions at the first stage are 1,800 lb/sq.in. at 1,000°F., with reheat temperatures of 1,000°. These conditions can be achieved using a direct cycle system.

Fossil-Fired Superheater

The next step is superheating to 1,000°. A superheater using nuclear fuel could be designed for this purpose, but this second reactor would have a whole new set of problems to be solved and would be prohibitive economically. The most realistic and available solution is to use a fossil-fired superheater. In addition to superheating steam before it goes to the first stage of the turbine, the superheater is used to reheat steam to 1,000°F. after it passes through the first section, and before it is fed back into the second section of the turbine.

Figure 1 shows the general operating principle and main components of the combination plant. In the core of the reactor, water circulates and boils at 2,115 lb/sq.in., dry and saturated. Canned motor pumps circulate the water through the core. A steam separating drum located in the loop between the reactor and the superheater separates water from the steam and ensures that only steam is passed on to the superheater. The water collected at the separating drum is returned to the reactor cycle. The steam from the superheater at 1,800 lb/sq.in. and 1,000°F. passes to the first section of the turbine. After passing through both stages of the turbine, the steam is condensed and returned to the reactor.

Reactor Details

The vital statistics proposed for this plant are as follows: the 34-ft high reactor vessel is 9¼ ft in inside diameter, and its walls are of 8-in. thick carbon steel with ¼-in. stainless steel lining. The core of the reactor is fuelled with about 26½ tons of uranium fabricated into small pellets. This uranium is enriched to about 2 per cent.

The superheater with its auxiliary equipment stands 146 ft high and is 76 ft × 65 ft in rectangular dimensions. This superheater can be fuelled

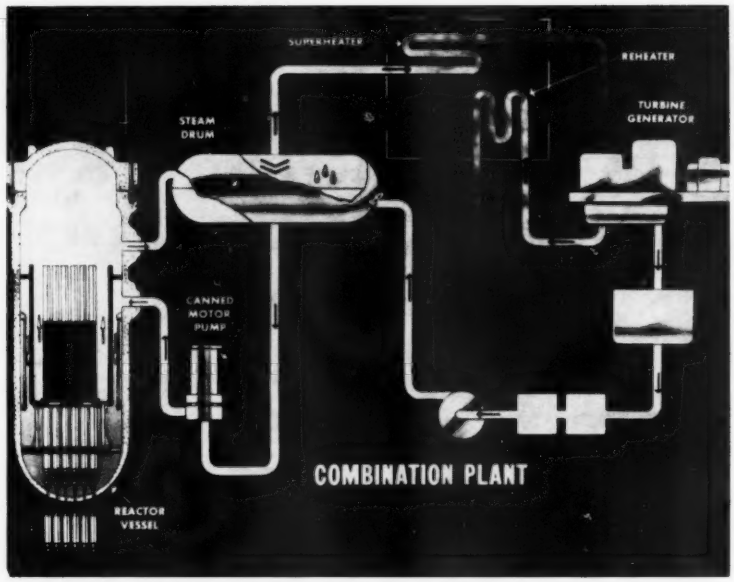


Fig. 1—An economic plant using this system could be built immediately, state Westinghouse

with either oil, gas or coal—the choice depending on individual utility economics.

The nuclear portion of the plant contributes about 300 MW(t) and the superheater about 220 MW(t) to the net power output of the plant. Together, they would produce an electric gross output of 225 MW. The total heat rate of this plant would be 9,040 B.t.u./kWh, net.

Immediate Application

Work towards construction of this plant could be started immediately, and could be in operation four years from the date of the contract. Feasibility studies indicate solutions to the major technical problems presented by this plant-type. In the area of control, for example, it was found that the 2,000 lb/sq.in. open cycle reactor would be easier to control than one at 1,000 lb/sq.in.

As with any open cycle plant, there is the problem of possible oxygen corrosion in the condensing stages of the turbine. But in this plant, studies indicate, because of the high initial reactor pressure and the superheat cycle, the oxygen concentration is only about 1 per cent. of that in a 1,000 lb/sq.in. dry and saturated steam plant.

Data for 225 MW Gross Combination Nuclear Power Plant

Power Rating	
Net, electrical	215 MW
Reactor contribution	60 per cent.
Superheater contribution	40 per cent.
Turbine Generator	
Operating pressure	1,800 lb/sq.in. gauge
Operating temperature	1,000°F/1,000°F.
Type	Tandem compound triple flow
Recirculating Pumps	
Number	4
Design pressure	2,500 lb/sq.in. abs.
Flow, gal/min each	12,500
Superheater and Reheater Unit	
Type	Pressurized furnace
Overall dimensions	146 ft × 76 ft × 65 ft
Fuel Assembly	
Type	Rod bundles
Fuel material	UO_2
Clad material	Zr-2 or stainless steel
Fuel	Pellets
Reactor Vessel	
Material	Carbon steel with stainless steel clad
Design pressure	2,500 lb/sq.in. abs.
Inside diameter	9 ft 3 in.
Overall length	*c.* 34 ft
Thermal and Hydraulic	
Operating temperature	Dry and saturated
Reactor operating pressure	2,100 lb/sq.in.
Steam Separators	
Number	2
Design pressure	2,500 lb/sq.in. abs.
Inside diameter	78 in.
Overall length	21 ft

Finally, the question of controlling the reactor and superheater together appears to be difficult, but feasibility studies suggest several solutions.

Now to economics. As a set of ground rules, the figures are based on a 90 per cent. load factor; 12.5 per cent. annual charges; fossil fuel costs of 30 cents per million B.t.u.; and plutonium credit of $12/gm, and 0.5 mills for indirect costs.

Under these conditions, the direct cycle nuclear power plant with fossil-fired superheat and reheat will produce electric power for 7.3 mills/kWh. These costs break down as follows: 3.4 mills in capital investment; 2.7 mills for fuel; 0.5 mills for indirect costs, and 0.7 mills for operation and maintenance. The 2.7 mill fuel figure is based on current costs and using 30 cents/million B.t.u. oil in the superheater, which is good average. Coal might cost less in itself but the attendant capital investment in rails, storage, ash disposal, etc., would bring the actual cost to about the same figure.

Fossil Fuel Costs

It is important to note that fossil fuel costs affect the total power cost estimates of the combination plant. Naturally, as fossil fuel costs rise, the economical advantage of this plant over totally fossil-fired plants will become less distinct. Specifically, at 40 cents/million B.t.u., power cost on the combination plant will rise to 7.7 mills/kWh; at 60 cents to 8.6 mills/kWh. This may seem at first to be a disadvantage, but compare it to the estimates of the rise in power costs on a completely fossil-fuelled plant. At 30 cents/million B.t.u., the average cost/kWh is 6.6 mills; at 40 cents, 7.4 mills. But at a fossil fuel cost of 60 cents, the power cost is 9.2 mills, and from then on the gap widens rapidly.

A Stage Ahead

The fundamental superheat concept, namely, obtaining more power from each lb of steam, is responsible for the combination plant and it leads to Westinghouse's second recommendation — the all-nuclear plant with integral superheating. In this plant, called the Integral Boiling and Superheating Reactor, the water is both boiled and then superheated within the reactor core. No separate unit for superheating is required. This plant is farther in the future than the combination plant; Westinghouse engineers envisage a full-scale plant of this type to be operating in 1975.

The operating principle of such a reactor type is shown in Fig. 2. A number of pressure tubes is inserted into the centre and around the periphery of the centre of the reactor, which is essentially a large block of graphite. Smaller rods holding the nuclear fuel are inserted into each pressure tube, and between these small fuel rods there is enough room for the coolant water to flow. A carbon-steel vessel, through which the pressure tubes extend, surrounds the core.

In operation, circulating water enters the centre region boiling tubes and is rapidly heated as it passes through the fuel region. This heated mixture of water and steam moves on up to one of four steam drums located above the reactor. The separated water is returned to the bottom of the boiling tubes in the centre region of the reactor; while the separated steam flows into the upper end of the superheating tubes located in the perimeter area of the core. The superheated steam collects in a header and then flows directly to the turbine.

20 MW Integral Boiling Superheat Reactor

Power Rating	
Net, electrical	20.0 MW
Fuel Assembly	
Type	Rod bundles
Fuel material	UO_2 pellets
Core Design	
Number of pressure tubes, total	*c.* 80
Number of tubes, superheat region	*c.* 24
Number of tubes, boiling region	*c.* 56
Pressure tube design condition (superheat region)	1,100 lb/sq.in. gauge, 1,000°F.
Pressure tube design condition (boiling region)	1,200 lb/sq.in. gauge, 650°F.
Reactor Tank	
Design condition	100 lb/sq.in. gauge, 650°F.
Material	Carbon steel
Outside diameter	12.5 ft
Wall thickness	½ in.
Steam Conditions	
Throttle temperature	900°F.
Throttle pressure	865 lb/sq.in. abs.
Graphite Core	
Cylinder height	*c.* 14 ft
Cylinder diameter	*c.* 11 ft
Steam Drum	
Design condition	1,200 lb/sq.in. gauge, 600°F.
Outside diameter	4 ft
Length	11 ft
Number required	2
Circulating Pump	
Number required	2
Capacity	2,570 gal/min
Helium Circulator	
Number required	1
Inlet temperature	740°F.
Capacity	14,300 lb/hr

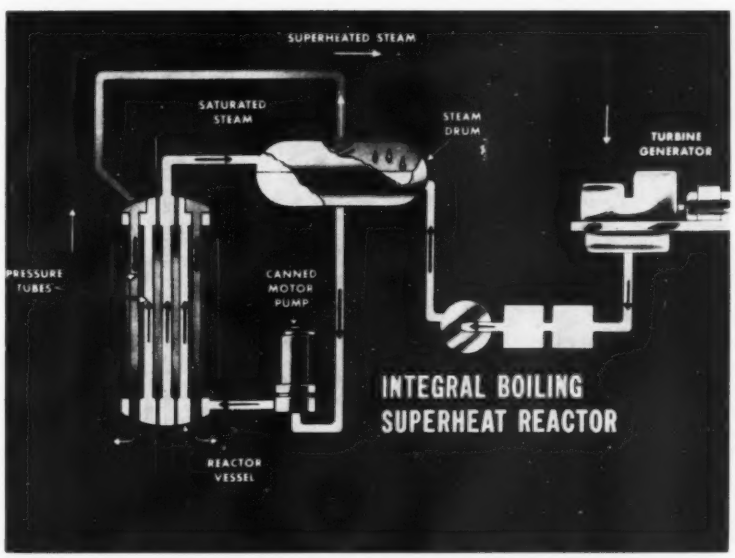
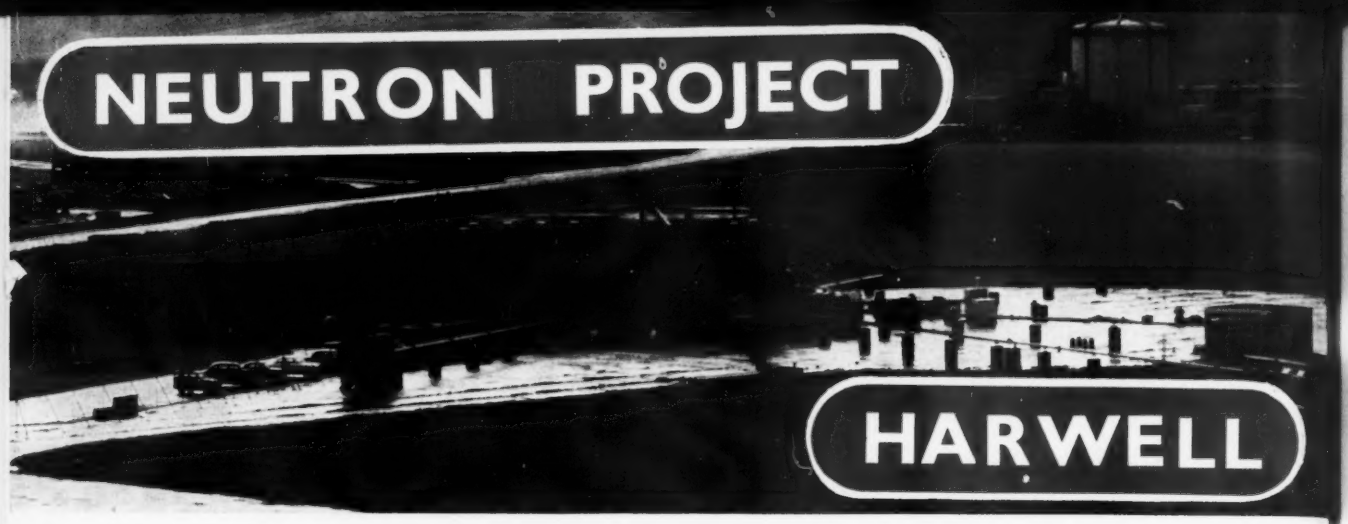


Fig. 2—A thorough research and development programme would have to be carried out on this system before it could be applied to a large-scale plant

This article will be concluded next month when the third system will be discussed.



THE Atomic Energy Research Establishment at Harwell have just brought into operation an entirely new and unique laboratory. Designed to produce information which will be great value in the design and improvement of nuclear reactors and to offer wide scope for basic research into nuclear structures, it is equipped with a high intensity pulsed source using a neutron booster together with what is probably the most extensive range of neutron " time-of-flight " spectrometers in the world.

With this equipment scientists will be able to undertake work previously possible on only a limited scale, using high flux reactors and cyclic accelerators. The new laboratory, called the neutron project laboratory, is under the supervision of the nuclear physics division of the AERE and was designed to their specifications.

Necessity for Research

It is very important to be able to predict the rates at which various reactions will proceed inside a reactor, and information of ever increasing accuracy is needed to calculate the behaviour of nuclear power stations throughout their life. It is, for example, relatively easy to calculate the amount of fuel required to make a reactor become critical, but much less easy to predict its condition after running for a number of years. As most of the nuclear processes occurring in a reactor involve neutrons, we must measure the way in which neutrons interact with the atoms that make up the core of the reactor.

We must find, for example, the probability that a neutron will be lost by capture, will cause a further fission, or will merely be scattered in a nuclear collision. Furthermore, since neutrons of different energies occur in a reactor, these probabilities must be measured as functions of neutron energy so that the appropriate averages may be taken for different reactors. Before such averages can be taken, we also need to know the energy spectrum of neutrons present in the reactor, and a complementary set of experiments is required on the behaviour of neutrons in moderators to check the theory used to calculate these spectra.

Not all of the nuclear properties involved in making reactor calculations are however readily amenable to direct measurement, and it is here that basic research into nuclear structure is of great practical use. Such research involves the study of nuclear energy levels and their properties and leads to the construction of " nuclear models." These models are of great interest in theoretical physics, and can be used to predict the behaviour of nuclei in circumstances where a direct measurement is impossible or excessively difficult.

The equipment installed in the neutron project laboratory will be used to provide information in all of these fields: it will yield accurate data on materials used directly in reactors, it will enable reactor spectra to be measured and predicted, and it will make possible many detailed studies of the interaction of neutrons with nuclei leading to the testing and further development of nuclear theory.

" Time-of-Flight "

One of the difficulties of measurements with neutrons is that accurately monoenergetic sources are not easily available below 50 keV (and this is an energy region of particular interest to the reactor designer), and also, as the neutron has no charge, it is not possible to separate out neutrons from a mixed source by means of a magnetic spectrometer as is done for charged particles A different method has therefore to be used, and one of the most successful is the well known " time-of-flight " method. In this method a *pulsed* source of neutrons is used and the neutrons allowed to pass along a long evacuated tube (the " flight path ") to meet a detector placed at its end. Neutrons of all energies start along this tube at the instant of the pulse, but due to their differing velocities they arrive at the detector at different times. Thus by using an electronic timing mechanism to record not only the behaviour of a neutron on arrival, but also its *time* of arrival it is possible to know exactly which velocity—and so which energy—of neutrons produces the effects observed. The velocities of neutrons are relatively high as may be seen from Table I.

Table I

Energy eV	Velocity metres/sec	Time to travel 50 metres (millisec)
0.0253	2,200	22.7
5.0	31,000	1.53
50.0	10^5	0.5
5,000	10^6	0.05
500,000	10^7	0.005

To get accurate measurements of velocity a very short pulse of neutrons is required and the neutrons should

A view of the neutron laboratory is shown at the top of this page. Stretching from one end of the building like tentacles are the " time-of-flight " tubes. In the background is the high flux reactor DIDO, which is also used for " time-of-flight " experiments

be allowed to travel over as long a flight path as possible before reaching the detector. However, putting the detector a long way away means that only a small proportion of the neutrons produced ever reach it, and so an extremely powerful source of neutrons is required.

750 Pulses per Second

The pulsed source in the Harwell neutron project is a travelling wave linear accelerator which produces bursts of electrons that have been accelerated up to an energy of about 30 MeV. These bursts are normally $\frac{1}{4}$ microsecond in duration, carry an electron current of between 0.3 amps and 0.4 amps during the burst, and occur at a rate of up to 750 pulses/sec. The electrons are allowed to fall on a mercury target serving the dual purpose of producing X-rays and removing the heat caused by stopping the beam. The X-rays are then absorbed in uranium to produce neutrons by photo-disintegration and by photo-fission.

A factor of ten increase in the neutron output is obtained by making the uranium into a sub-critical U-235 assembly which multiplies up the primary neutrons liberated on absorption of the X-rays. Care has been taken in designing this assembly to prevent the pulse being lengthened by the multiplication process as otherwise the energy resolution of the instrument would be spoiled and the whole advantage of the extra intensity lost. Table II gives performance figures for the source.

During the pulse the fissile assembly is reacting at about 8 MW power, although due to the pulsed nature of the source the mean power will never rise above $2\frac{1}{2}$ kW. This means that it can be very small in size compared to a conventional 8 MW reactor and it is possible for the beam tubes to " look at " its whole surface.

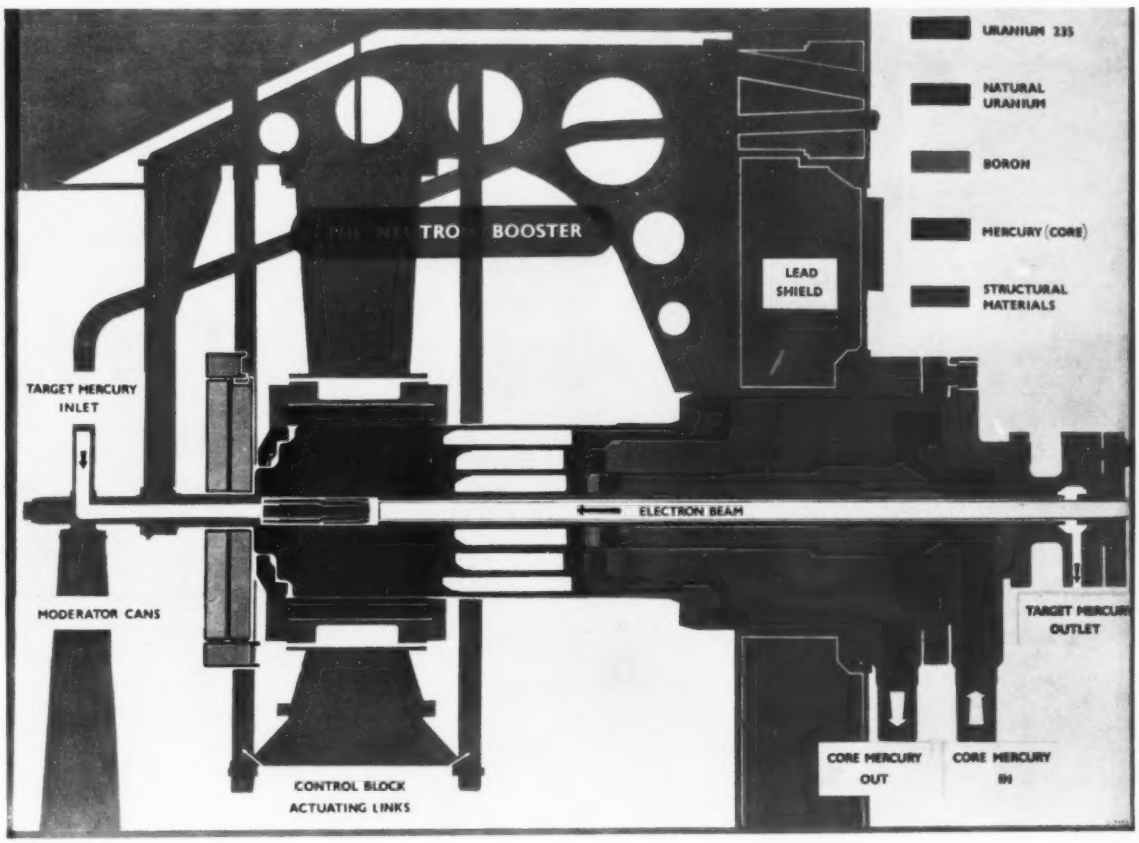
The sub-critical assembly is housed in a specially built concrete cell in the walls of which are nine " neutron windows " to which "time-of-flight" tubes are connected, each tube carrying an experiment. Some of the windows have two tubes connected to them.

The beam from the accelerator can be magnetically deflected before

Table II

Number of sections in linear accelerator ..	6
Length/section ..	1m
Power input/section (peak)	6 MW
Frequency	2,998 M/cs
RF power source ..	Klystron amplifiers driven by magnetron
Beam Energy ..	25 to 35 MeV according to load
Peak beam current (best achieved) ..	400 mA
Normal running beam current	350 mA
Pulse length (variable)	0.2 to 2 microsec
Pulse repetition frequency (variable) ..	Up to 750 pulses/sec
Rate of neutron output during pulse (calculated value for maximum beam current actually achieved, multiplication by booster not taken into account)	2×10^{15} neutrons/sec
Rate of neutron output using fissile target ..	2×10^{17} neutrons/sec
Fuel	Highly enriched uranium-235

(*Below*) **Diagrammatic section of the neutron booster**



it reaches the sub-critical uranium assembly, if required, on to non-boosted targets. These targets and the magnets are housed in a concrete cell situated between the accelerator and the booster. It has six neutron windows, three on either side, to which further " time-of-flight " tubes can be connected.

The " time-of-flight " tubes from both target cells vary in length up to 200m. A 300m long tube will shortly be added.

Advantages of " Neutron Project "

Very successful pulsed sources for carrying out experiments of the type for which the laboratory has been built have been operated using betatron, cyclotron, and synchro-cyclotron accelerators. To use such machines for a continuous programme of pulsed " time-of-flight " work, however, would be grossly uneconomical. Furthermore, the linac technique as exploited in the Harwell neutron project gives a higher pulse rate repetition rate than is generally possible with cyclic accelerators. An added advantage of using a linear accelerator is that laying out a multipath " time-of-flight " tube system is simplified.

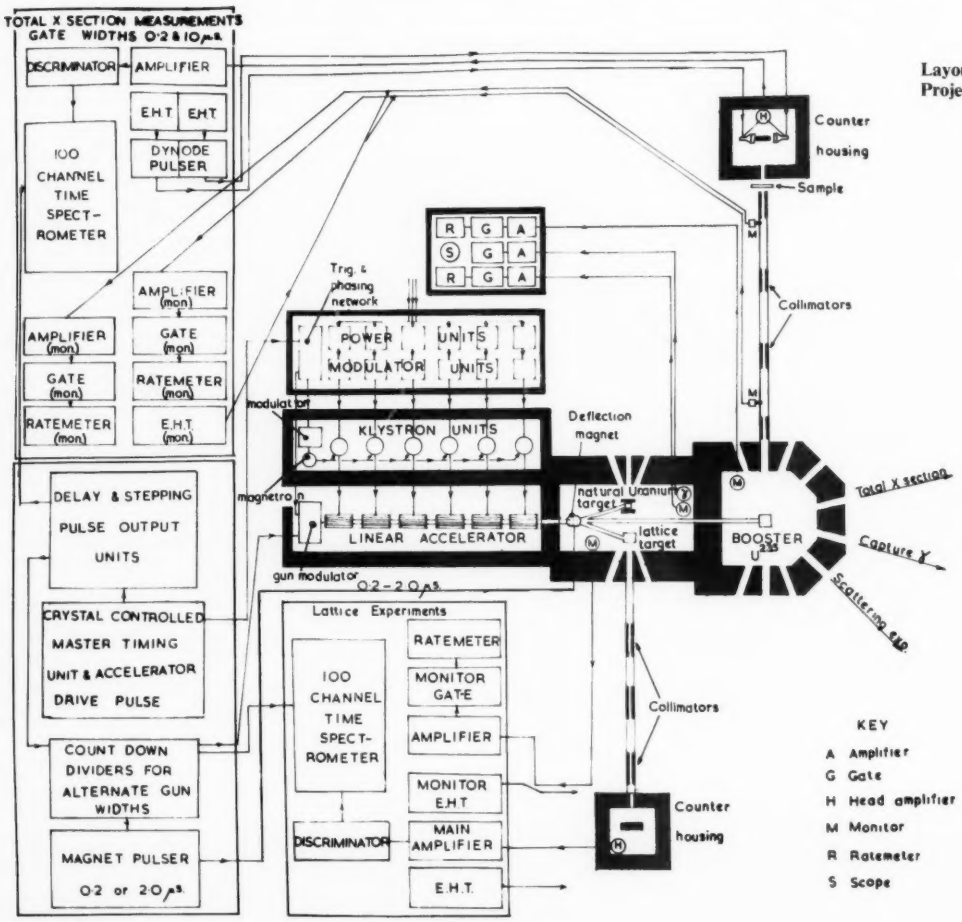
Pulsed " time-of-flight " experiments have, of course, also been successfully carried out using a neutron chopper in conjunction with a high flux reactor. Only one flight path is available to one chopper, however, and so simultaneous experiments cannot be carried out. An added disadvantage is that there is a continuous background of pile-generated gamma rays emerging from the chopper to contend with. Furthermore most choppers require a widely diverging beam, which is disadvantageous for all but total cross-section work.

In specifying an accelerator for their work the neutron project scientists defined the minimum pulse current required and placed some restriction on the energy spectrum. From previous experience it seemed likely that this specification would be met by an accelerator which gave a pulse current of 750 mA at a mean energy of slightly over 25 MeV.

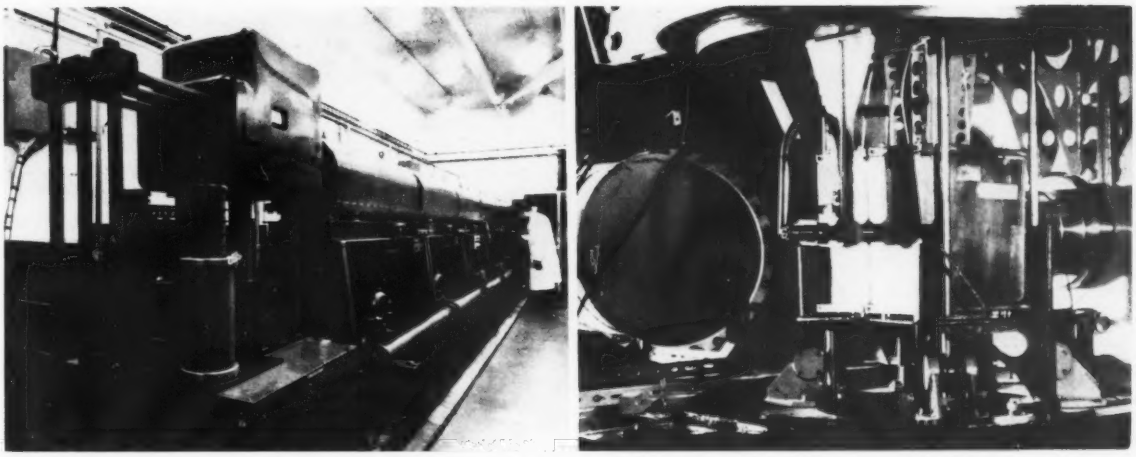
Four Klystrons Enough

Theoretical considerations showed that an efficiency of 80 per cent. for the conversion from RF to electron beam power was reasonable, and practical results, at lower efficiencies, had agreed with theory, so that it might be possible to achieve the output desired with a peak RF power of 24 MW. As the RF power was to be supplied by klystron amplifiers rated at 6 MW peak, the minimum number required would be four.

A beam current of 750 mA, however, was over twice as great as that of any accelerator built at that time, and some margin of safety seemed desirable, to allow for factors which had not been taken into account in the theoretical assessment. It was



Layout of the Neutron Project showing instrumentation



(*Left*) **The linear accelerator. This was constructed in collaboration with UKAEA scientists by the Metropolitan-Vickers Electrical Co., Ltd.**
(*Right*) **The neutron booster with the moderator tanks in position. Left background is one of the neutron windows to which "time-of-flight" tubes are connected**

therefore decided to design for a beam current of 1 amp, which would require peak RF input of at least 31 MW. This required the use of six klystrons, but if the design current had been reduced to about 900 mA, five klystrons could have been used. Designs were prepared for both cases, the overall length of corrugated waveguide being kept constant.

The design for six klystrons needed a conversion efficiency of 75 per cent. for an output current of 1 amp at a mean energy of 27 MeV. Such an accelerator would have a flatter regulation curve and be less frequency sensitive than one designed for five klystrons. From these and other considerations, it was decided to go ahead with the six klystron design. In this, the power from each klystron, except the first, is fed to a 1m length of corrugated waveguide, which has a phase velocity equal to c, the velocity of light, at the design frequency. Any power remaining at the end of the waveguide is absorbed in a water-cooled resistive load. The first section of waveguide is 1.2 m long and incorporates a bunching section in which the phase velocity is initially 0.4c, to match the velocity of the injected electrons, and increases along the section, as the velocity of the accelerated electrons increases.

The Sections

Each section of corrugated waveguide of the finished accelerator is built up of a number of cup-shaped copper pieces, which spigot into each other, and are clamped together by long tie-bars. A focusing coil, wound from copper tubing, is fitted round the assembled waveguide, which is mounted on to a steel plate by means of the waveguide transformer sections which serve to feed power into and out of the corrugated waveguide. This steel plate, together with a steel cover, from the vacuum chamber for each section, and a large oil diffusion pump, with baffle and valve, is suspended from the centre of each plate. The six frames are bolted together, and the vacuum chambers are joined by metal bellows, to allow free passage of the electron beam.

The electron gun is mounted directly on the vacuum chamber of the first section. This gun is of the triode type, with a steady potential difference of about 45 kV maintained between cathode and anode.

The grid is biased negatively so that no current is injected except when positive pulses of about 3 kV are superimposed. Pulses of 0.2, 0.5, 1 and 2 microseconds duration are available. The RF pulse length is longer than the gun pulse, to allow the fields to build up in the corrugated waveguide, and to ensure that the timing and shape of the electron pulse is determined by the gun pulse. It is normally 2.5 microseconds, but can be reduced to 1.25 microseconds when the shorter gun pulses are used, to reduce power consumption.

The klystron amplifiers are of the three cavity type, rated to give 6 MW peak and 9 MW mean power output at 10 cm wavelength. They are mounted on combined pulse transformer and vacuum pumping units, in a room running alongside the

Dr. Egon Bretscher, who as head of the nuclear physics division at Harwell, has overall responsibility of the Neutron Project. Of Swiss birth, Dr. Bretscher has been at Harwell since 1947 and in charge of nuclear physics since 1948

(*Below*) **Two senior scientists intimately concerned with the Neutron Project. Dr. Michael J. Poole (*left*) has been with the nuclear physics division at Harwell since 1956. Before that he was at Los Alamos. Was born in 1922 and educated at Manchester Grammar School and Trinity College, Cambridge. His colleague, Dr. E. R. Rae (*right*) joined Harwell in 1952 after a spell as a university lecturer. Has worked on neutron physics ever since. Born in 1920 he was educated at Glasgow University**

accelerator room, so that the waveguides carrying the RF power to the accelerator can be kept short.

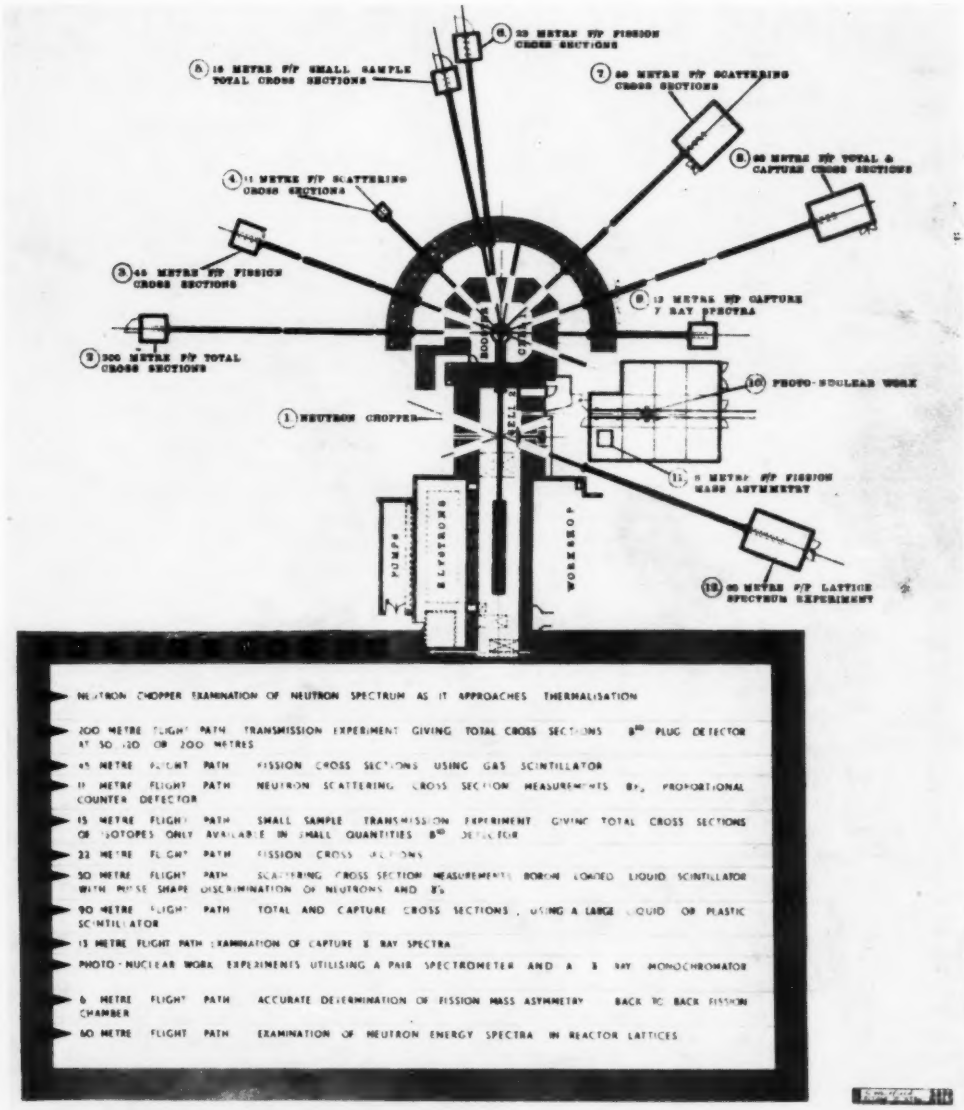
Spare Valve as Standby

At the time the accelerator was designed, only continuously evacuated klystrons had been tested, and although sealed valves were under development, it was decided to design for the use of pumped valves, making provision for a change to sealed valves when they were shown to be satisfactory. There are seven pumping units in the klystron room, so that a spare valve can be pumped out, the cathode converted, and conditioned ready for use.

When one of the klystrons feeding the accelerator fails, the complete unit can be removed by means of a wheeled trolley, and replaced by the spare. Provision is made for keeping the vacuum pumps running during the changeover. The klystrons in use are driven by a magnetron, through directive feeds from a common drive line. An attenuator and phase shifter is fitted in each branch to set the correct drive conditions. The magnetron gives pulses of 1MW peak for 3 microseconds, at a frequency of 2,998 Mc/s, the design frequency for the accelerator.

Modulator Problem

Each klystron requires HT pulses of about 90 amps at 200 kV which set a difficult problem for the modulator design, as no switch valve was available which would handle the required 18 MW of power. Spark-gap modulators had been used for the initial development of the klystrons, but they were not very satisfactory and required constant adjustment and cleaning. The problem was solved by designing modulators to use four of the largest hydrogen thyratrons available, each used to discharge a separate pulse-forming network through each of the four primaries of a combining pulse transformer, the output of which is sufficient to feed a klystron. Each modulator has an associated power supply unit, to recharge the pulse forming networks, which supplies a maximum of 5 amps at 9 kV to allow the klystrons to be run at


(8) 22 METRE F/P FISSION CROSS SECTIONS
(5) 15 METRE F/P SMALL SAMPLE TOTAL CROSS SECTIONS
(7) 50 METRE F/P SCATTERING CROSS SECTIONS
(6) 90 METRE F/P TOTAL & CAPTURE CROSS SECTIONS
(4) 11 METRE F/P SCATTERING CROSS SECTIONS
(3) 65 METRE F/P FISSION CROSS SECTIONS
(2) 200 METRE F/P TOTAL CROSS SECTIONS
(9) 13 METRE F/P CAPTURE γ RAY SPECTRA
(10) PHOTO-NUCLEAR WORK
(1) NEUTRON CHOPPER
(11) 6 METRE F/P FISSION MASS ASYMMETRY
(12) 60 METRE F/P LATTICE SPECTRUM EXPERIMENT
BOOSTER CELL
PUMPS
KLYSTRONS
WORKSHOP
NEUTRON CHOPPER EXAMINATION OF NEUTRON SPECTRUM AS IT APPROACHES THERMALISATION
200 METRE FLIGHT PATH TRANSMISSION EXPERIMENT GIVING TOTAL CROSS SECTIONS B10 PLUG DETECTOR AT 50 120 OR 200 METRES
65 METRE FLIGHT PATH FISSION CROSS SECTIONS USING GAS SCINTILLATOR
11 METRE FLIGHT PATH NEUTRON SCATTERING CROSS SECTION MEASUREMENTS B10 PROPORTIONAL COUNTER DETECTOR
15 METRE FLIGHT PATH SMALL SAMPLE TRANSMISSION EXPERIMENT GIVING TOTAL CROSS SECTIONS OF ISOTOPES ONLY AVAILABLE IN SMALL QUANTITIES B10 DETECTOR
22 METRE FLIGHT PATH FISSION CROSS SECTIONS
50 METRE FLIGHT PATH SCATTERING CROSS SECTION MEASUREMENTS BORON LOADED LIQUID SCINTILLATOR WITH PULSE SHAPE DISCRIMINATION OF NEUTRONS AND γ's
90 METRE FLIGHT PATH TOTAL AND CAPTURE CROSS SECTIONS, USING A LARGE LIQUID OR PLASTIC SCINTILLATOR
13 METRE FLIGHT PATH EXAMINATION OF CAPTURE γ RAY SPECTRA
PHOTO-NUCLEAR WORK EXPERIMENTS UTILISING A PAIR SPECTROMETER AND A γ RAY MONOCHROMATOR
6 METRE FLIGHT PATH ACCURATE DETERMINATION OF FISSION MASS ASYMMETRY BACK TO BACK FISSION CHAMBER
60 METRE FLIGHT PATH EXAMINATION OF NEUTRON ENERGY SPECTRA IN REACTOR LATTICES

Layout of Neutron Project experiments

their full mean power rating. Grid controlled rectifiers are used to give smooth control of the HT voltage, and allow fast-acting protective schemes to be used.

All controls are brought through to the control room, except those for the vacuum systems, which are operated locally. Controls used only for initial running-up are mounted on racks, but all those needed for the actual operation of the machine as a whole are mounted on a control desk, which also carries some of the controls for the booster target.

Design Requirements

In designing the booster target the scientists had to take into account the following requirements:—

(1) To obtain the greatest efficiency from the assembly the X-ray must be produced at its centre. It was therefore necessary that the electron beam tube was led into the centre of the assembly together with the mercury cooling pipes, while at the same time keeping heat and neutron losses to a minimum. A leakage of neutrons would unduly increase the amount of fissile material required;

(2) The assembly must produce a useful multiplication;

(3) At the multiplication used the pulse must not be distorted to an extent that resolution is spoiled, otherwise an increase in flight path length will be required, and some of the benefit of the increased intensity will be lost. Some compromise is necessary at this point;

(4) The system must be intrinsically safe;

(5) The system must be so designed that it can be assembled safely without relying on theoretical estimates of critical size; and

(6) The spectrum of neutrons must be so modified (by moderators) that as many neutrons as possible lie in the energy range 1 eV to 50 keV. The presence of these moderators must not affect the pulse shape (again compromise is needed).

Plutonium would have been a more suitable material to have used in the booster than enriched uranium. However, as it was unavailable to the designers they had to keep to U-235. Plutonium would, of course, have posed some difficult safety problems.

Mercury Instead of Water

The core of the booster is made up of three annular cans of U-235 mounted concentrically round a mercury target backed by U-235. The cans are mercury cooled. It had been originally planned to use water as coolant, but due to the danger arising from possible oxidation of the steel used in the structure of the assembly it was decided to use mercury.

The Moderator Tanks

Around the core is a thin natural uranium reflector. This is divided equatorially into two parts, the top half being fixed and the bottom movable to act as a "control and safety block." The reflector is built up of from solid uranium end pieces canned in aluminium and supporting a ring of uranium rods. The "end reflector" nearest to the accelerator is contained in the fuel cans themselves and is integral with the core.

Around three sides of the core are the moderator tanks cans. These are shielded from the core by boron used to obviate the effect the moderator can have on the pulse length. The whole assembly is enclosed in a lead pot 12 cm thick and weighing 12 tons. The central part of this shield is supported on screw jacks and can be lowered to expose a 2 ft wide belt round the booster.

BOOK REVIEWS

Introduction to Probability and Statistics, by B. W. Lindgren and G. W. McElrath. Published by The Macmillan Co., New York—New York and London. Size 9 in. × 6 in. × 277 pp. Price 44s. 0d.

Anyone whose mathematical equipment includes a reasonable working knowledge of the integral calculus will find this volume by Lindgren and McElrath a really useful approach to the disciplines of probability and statistics. The authors have made the subject as attractive as possible by taking a middle course between the ultratheoretical and the completely down-to-earth, but they make no attempt to disguise the fact that statistics is not everybody's cup of tea. Indeed, it is frankly admitted to the student in a foreword that statistics in its many ramifications "is an exceedingly complex subject," and "you must be willing to work out problem after problem." In a word, this is a book for the serious, hard-working, hard-thinking student. There is probably no department of mathematics, pure or applied, where real thinking is so absolutely necessary. It is not a matter of mastering standard formulae, probability "models," etc., and applying them in mechanical fashion to this problem and that; it is an attitude of mind to think one's way through statistical analysis that is the real technique of this important subject. This volume contains five substantial chapters on probability full of sensible, worked examples which should give the student the right atmosphere and a sound mathematical basis for the collection and analysis of statistical data. With the excellent background given of probability theory, the student should enjoy the chapters on the presentation and description of data and on testing statistical hypotheses and the other sections on statistics. The authors' treatment of their subject fully justifies the book's title and the volume is likely to rank high among the best of introductions to this increasingly important sphere of mathematical science.

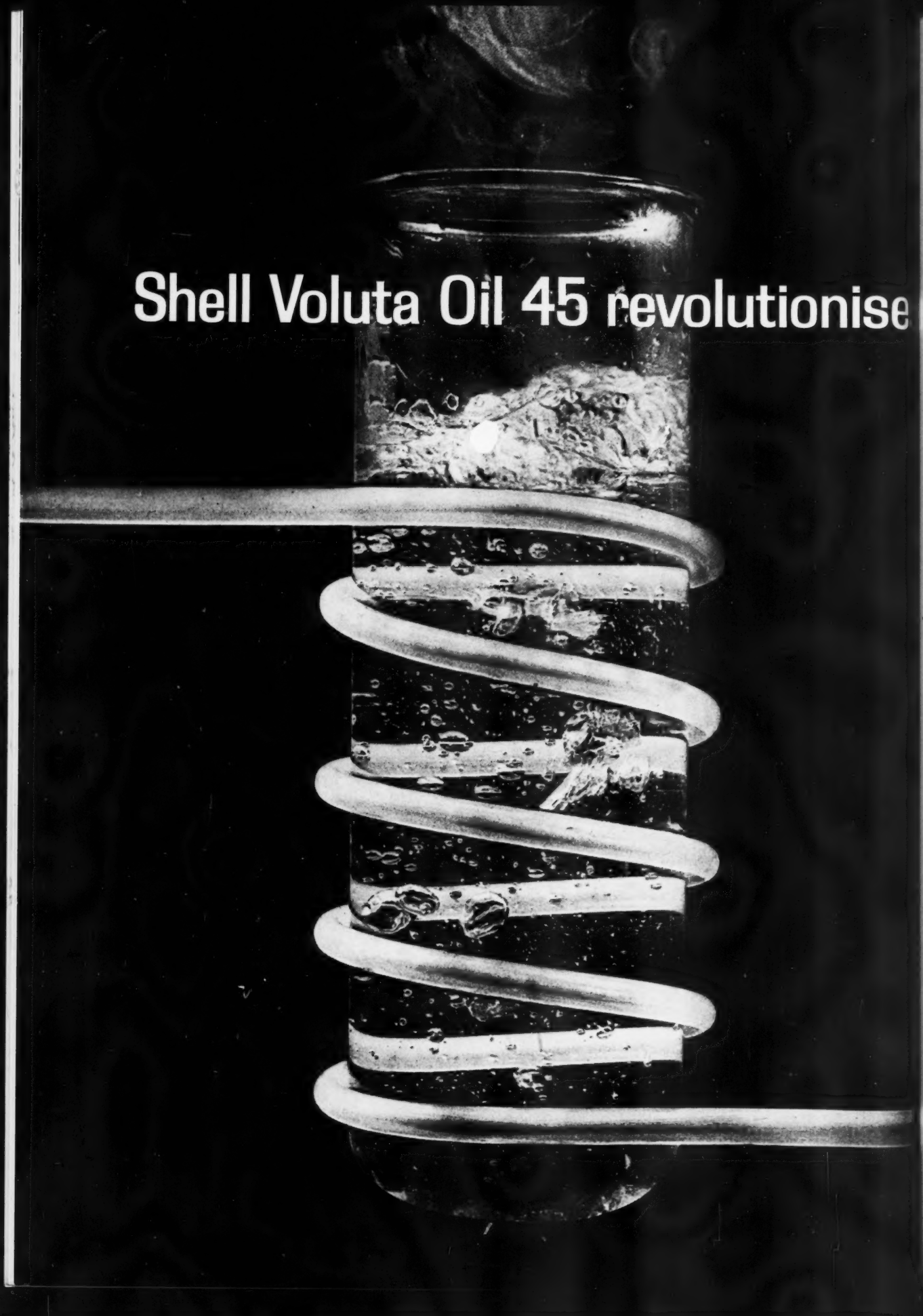
D.S.W.

The Industrial Challenge of Nuclear Energy—III: Proceedings of the Stresa Conference—Part I. Published by the OEEC European Nuclear Energy Agency. Size 9½ in. × 6 in. × 275 pp. Price 18s. 6d.

This first volume of the proceedings of the conference on industrial prospects in nuclear energy organized at Stresa last May by the European Nuclear Energy Agency provides a useful reference book for anyone seeking background knowledge to the national nuclear programmes and the role of various international organizations such as the World Bank and the International Atomic Energy Agency. Papers presented at four of the conference sessions are published together with the questions and answers that followed the papers and what are called "Interventions"—subsidiary papers presented by various participating countries and organizations. The first session represented a survey of European programmes, the second was devoted to the economics of nuclear power, and the third and fourth to different aspects of the financing of programmes. One of the papers given at the last of these sessions dealt with the financing of the American programme, the United States participating in the work of the OEEC as an associate member. The volume concludes with two useful annexes. The first is an estimate of nuclear energy production in Europe, 1958-65, made before the conference and since revised, and the other a study of the financing of nuclear energy programmes and relations between the State and Industry, similarly made before Stresa and since revised. The volume includes a pull-out colour map of Europe showing nuclear installations in OEEC countries.

TV for BERKELEY

PYE Ltd., of Cambridge have received an order from AEI-John Thompson Ltd., main contractor for the Berkeley power station, for two sets of reactor inspection television camera equipment. This means that Pye are now supplying this type of equipment for three out of four nuclear power stations being built in Great Britain, as well as one set for Latina in Italy.


Shell Voluta Oil 45 revolutionise h

se heat exchange practice

Before Shell produced Voluta Oil 45 it was thought that oils which were to be used for heat exchange purposes must have a high flashpoint —to reduce fire risk, and a high viscosity—to prevent excessive leakage through pump glands and to provide adequate lubrication for pump bearings at high temperatures. Heat exchange systems containing these viscous oils, however, were sluggish, particularly when started up from cold. The oil circulated slowly over the source of heat and suffered thermal decomposition, or "cracking". This, in turn, produced low flashpoint materials and carbon which insulated the heating surface.

Shell, therefore, began investigating the suitability of oils of lower viscosity and different chemical constitution. From this research was developed Shell Voluta 45.

Shell Voluta 45 contains hydrocarbons with a saturated ring structure which does not have the tendency that high viscosity straight chain paraffin hydrocarbons had—to break down at high temperatures. Because of its low viscosity Shell Voluta 45 heats up more quickly from cold and circulates more rapidly thus avoiding local overheating and thermal decomposition.

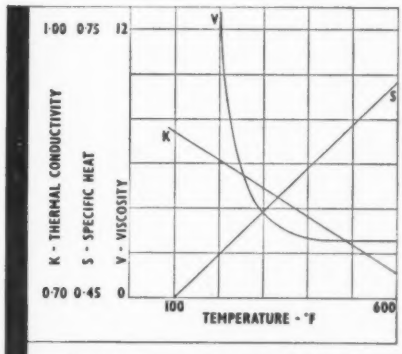
Shell Voluta Oil 45 has excellent heat transfer properties, good thermal stability and good lubricating properties. It is recommended for use in all closed heat transfer systems.

The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Laboratory research to compare the high temperature performance of various oils in a rig simulating practical conditions showed that when oils of varying viscosities were maintained at an average temperature of 325°C. for 200 hours, the closed flashpoint of the high viscosity oils had dropped to a lower figure than that of oils of lower viscosity, indicating that some thermal decomposition had taken place.

Experimental oils were subjected to Heat Stability Tests and to tests designed to measure the variation in heat transfer coefficient with time. The most promising of these oils was then given extensive field trials, both in Shell Installations and in industry. From this extensive research was developed Shell Voluta 45.



Physical properties of Shell Voluta Oil 45.
K. Thermal Conductivity—B.T.U./sq. ft. per hour per 1°F. per inch.
S. Specific Heat—B.T.U. per lb. per 1°F.
V. Viscosity—Kinematic centistokes.

SHELL

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Design of Large Gas Ducts*

by A. T. BOWDEN, BSc, PhD, and J. C. DRUMM, BE

Some of the problems encountered in the design of the large gas ducts associated with present-day nuclear reactors are outlined. Various ways of providing ductwork with flexibility are analysed and it is shown that a design involving the use of a combination of tied expansion bellows and cascaded corners is the most economic way of meeting the need for high flexibility and low flow pressure loss. The design of a large tied expansion bellows is discussed and an account given of the bellows now being installed in the gas circuits of the nuclear power station at Bradwell, Essex

THE Bradwell station was designed to give its rated power output with reactor inlet and outlet temperatures of 180°C. and 390°C. respectively, and with a maximum pressure of 132 lb/sq.in. gauge in the coolant gas. The pressure circuit was designed, however, to meet other operating conditions as well. These are as follows:—

(1) The design working condition giving an allowance on the conditions above to cater for contingencies. Pressure 147 lb/sq.in. Reactor 200°-420°C.;
(2) The operation of the reactor with one circuit isolated and therefore cold with the remainder at condition (1);
(3) A special duty condition under which the reactor inlet temperature is raised to 230°C. for some months while the pressure is 147 lb/sq.in.;
(4) The start up of the circuit isolated in (2). Under this condition the top duct line is assumed to heat up rapidly but the heat exchanger has a considerable time lag owing to its inner liner; and
(5) The cold draw condition at full pressure (147 lb/sq.in.) and an ambient temperature of 15°C. The condition is likely to arise only during commissioning of the plant. Normally the pressure will not exceed 60 lb/sq.in. in the cold condition.

A well-designed duct system for a gas-cooled reactor should perform its function of conveying the reactor coolant to and from the heat exchangers reliably with the economic minimum pressure drop in the gas flow, and without transmitting large thrusts to the reactor or heat exchanger shells. All vital equipment associated with the reactor and its pressure circuit should be designed to give reliable service for the full life of the plant and, if at all possible, should not require any maintenance during that period.

Cost of Each Circuit

The need for low pressure loss may be gauged from the fact that in a large station an expenditure of up to £5,000 on each heat exchanger circuit can be justified for any design feature which will reduce the circuit pressure drop by 0.1 lb/sq.in. This figure is based on the capitalized value of the circulator driving power saved over a period of 20 years as a result of reduced circuit resistance.

Again there are important economic reasons for keeping the magnitude of the thrusts applied to the reactor pressure vessel down to the lowest possible level. It is a mandatory requirement of both BS 1500 and the ASME Unfired Pressure Vessels Code that allowance be made for stresses due to moments and thrusts at nozzles when fixing the maximum permissible operating pressure for a vessel of given dimensions. Thus if the sum of the stresses due to pressure and to a moment at a nozzle is in excess of the design working stress for the vessel steel the pressure in the system must be reduced to bring the total stress at the nozzle down to the design working stress. Such a reduction in pressure could seriously increase the overall capital cost of the station.

For the conditions prevailing in the pressure circuit of a gas-cooled reactor there are probably only four practical solutions to the problem of providing large ducts with flexibility. In summary these are:—

(*a*) short-radius mitred ("lobster back") bends on single large-bore ducts;
(*b*) mitred bends on two or more smaller bore ducts in parallel for each heat exchanger circuit;
(*c*) corrugated ducts;
(*d*) single large-bore ducts with three tied expansion bellows in each line of ducting.

The most commonly adopted means of providing pipes with the necessary flexibility to absorb differential expansion is to incorporate a number of bends in each line. Pipe bends have a well-known property of being substantially more flexible when subject to external moments than the usual theory of elasticity indicates.

Flexibility Increase

This increased flexibility in a pipe bend is due to the fact that when a bend is subjected to a moment its cross-section becomes oval, thus greatly relieving the longitudinal bending stresses in the outside fibres of the bend and at the same time moving the point of maximum stress nearer to the neutral axis. The altered distribution of bending stress leads to a decrease in the moment of resistance of the bend.

*Extract from a paper, "Design and Testing of Large Gas Ducts," presented to the Institution of Mechanical Engineers.

Both the altered stress pattern and the increased flexibility which accompanies it can be simply related to a bend characteristic λ defined as:—

$$\lambda = \frac{t}{r} \times \frac{R}{r}$$

where t is the thickness of the bend wall, r the mean radius of the bend cross-section, and R the radius of curvature of the bend centre line.

Table I

	Ducts		Condition
	Top	Bottom	
Thrust, ton	10.7	17.1	Hot with pressure
Moment at reactor, ton/ft	139	313	Hot with pressure
Maximum flexure stress in bends, ton/sq.in.	7.8	3.75	Hot with pressure
Thrust, ton	11.6	22.3	Cold with pressure
Moment at reactor, ton/ft	118	400	Cold with pressure
Maximum flexure stress in bends, ton/sq.in.	9.1	5.1	Cold with pressure

Estimates Possible

A large amount of theoretical and experimental work has been carried out on pipe bend flexibility and stress distribution since the publication of von Karman's first paper[1] on the subject in 1911. Sufficient information on the performance of bends is now available to permit the making of a fairly realistic estimate of the possibilities of designing a reactor duct system which relies principally on the ovalization of the cross-section of its bends to provide flexibility. However, it should be pointed out that most of the experimental work on pipe bends which is reported in the literature was carried out on small-bore pipes with fairly large ratios of thickness to diameter. Further tests, preferably on a large-scale bend, would be necessary to prove that the results of this work can be extended to bends in pipes with thickness to diameter ratios in the range 1/100 to 1/150.

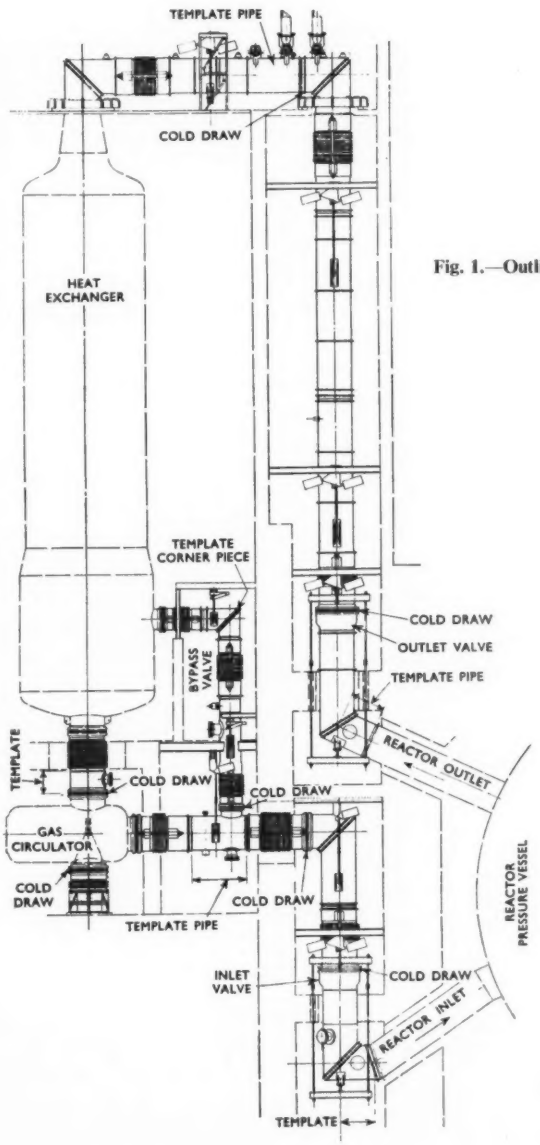


Fig. 1.—Outline of reactor ductwork

This test would also enable a check to be made on the magnitude of the effects produced by commercial quality welding, by inaccuracies in the fit-up of the mitres in the case of a mitred bend and by variations in tangent length.

A general examination of the problem of designing reactor ductwork with flexible bends leads to the conclusion that a compact layout with minimum thrusts is best obtained by using bends of comparatively short radius of curvature. In the work described below bends with a radius of one pipe diameter are considered. The fatigue tests on pipe bends carried out by Markl[2,3] and the work on short-radius bends by Gross and Ford[4,5] permit designs with bend radii of this order to be made with some degree of confidence.

Optimum Radius

It is felt, however, that the available knowledge on bend flexibility does not justify the use of a smaller radius. For a 60 in. duct with a wall thickness of $\frac{1}{2}$ in., the value of the bend characteristic λ corresponding to this curvature is 0.033 and this is close to the lower limit of the range which has been well covered by experiment.

Right-angle bends for ducts of 60 in. bore are usually fabricated

from a number of short duct lengths with suitably mitred ends.

The majority of the work reported in the literature on pipe-bend flexibility and stresses was carried out on smooth bends made by drawing or pressing. There is some evidence to indicate (Gross and Ford[5], Zeno[6] and Markl[2,3]) that stresses and flexibilities for mitred bends can be predicted fairly well by the theory of curved pipes provided that long tangents and four or more mitres are used for a right-angle bend. However, the general consensus of opinion seems to be that mitred bends are rather less flexible and are subject to higher stresses than smooth bends of the same leading dimensions[7]. The usual expressions for the flexibility factor k† and stress intensification factor J for a smooth bend are:—

$$k=1.65/\lambda$$

and

$$J=0.90/(\lambda)^{2/3}$$

For a 60 in. bore bend with a $\frac{1}{2}$ in. thick wall a radius ratio of 2, $\lambda=0.033$ and hence $k=50$ and $J=8.75$.

The work of Rodabaugh and George[8] indicates that bends with a small ratio of thickness to diameter are substantially increased in stiffness by internal pressure. On the other hand the stress intensification factor is reduced by internal pressure. Using the expressions given by these authors the flexibility factor for the bend drops from 50 to 33 when the internal pressure is raised by 147 lb/sq.in. Correspondingly, the stress intensification factor is reduced from 8.75 to 5.13.

A Ducting Example

Some figures are quoted in Table I for a duct layout similar to that shown in Fig. 1 but with the bellows removed and the stiff corners replaced by flexible mitred bends with a radius of curvature equal to the mean diameter of the pipe. The pipe wall thickness was assumed to be 0.5 in. and the bends were assumed to have the same flexibility and stress intensification factors as a smooth bend. The figures indicate the order of magnitude of the forces and moments associated with the use of short radius flexible bends on reactor ductwork. However, it should be pointed out that this particular duct layout could not be adopted in practice as it would mean placing highly stressed flexible bends in positions where they could not be inspected owing to radiation streaming from the core.

The flexure stresses quoted above for the top duct bends would be acceptable in bends made of a weldable low-alloy steel such as 0.5 per cent. molybdenum, 0.25 per cent. vanadium with an ultimate tensile stress (u.t.s.) of 38 ton/sq.in. at room temperature and 33 ton/sq.in. at 420°C., assuming these bends are designed to meet the requirements of the 1955 ASA B31-1 Code for Pressure Piping. The bends in the bottom ducts could be made of mild steel since the stresses are much lower and the ducting is relatively cool.

Stress Tests Limited

It is difficult to calculate the magnitude of the stresses induced in the wall of a spherical pressure vessel by a given moment or thrust applied at a nozzle. The amount of experimental work reported on this subject is limited. Detailed analysis of the stress pattern round a nozzle subject to moments and thrusts is difficult in the case of a simple pipe welded to the surface of a sphere, and the problem is further complicated by the use of a heavy forged compensating ring. A method of calculating local shell stresses due to moments and thrusts applied at nozzle is given in Kellogg[7]. The solution is based on an approximate treatment similar to that used for a beam-on-an-elastic foundation, and results in the following expression:—

$$f=\frac{1.17\sqrt{R}}{t^{1.5}}[F_1+1.5F_2]$$

where f is the local longitudinal bending stress in the shell, lb/sq.in., R the meridional radius of the shell, in., t the effective local thickness of the shell, in., F_1 the unit loading due to applied bending moments, lb/in. $=M/\pi R_n^2$, where M is the moment, lb/in., and R_n the mean radius of nozzle connection, in., F_2 the unit loading due to a radial thrust, lb/in., and $=P/2\pi R_n$, where P is the total thrust, lb.

Wells[9] gives a very similar expression based on an analysis carried out by Timoshenko[10] of the stresses produced by a ring loading on a cylinder. Wells gives an interesting comparison of the stresses calculated by his expression with those actually measured during a strain gauge investigation carried out by Schoessow and Kooistra[11] on the effect of moments and thrusts applied to pipes attached radially to two large cylinders.

The figures quoted show that the expression given above overestimates the local stresses by factors ranging from 1.4 to 1.5 for a moment and from 2.3 to 2.5 for a radial thrust. However, an examination of Schoessow and Kooistra's results indicates that there were strains present in the walls of the vessels which were substantially higher than those recorded. This is due to the fact that strain gauges were not positioned sufficiently close to the branch pipes.

In the case of reactor pressure vessels, stresses due to direct thrusts are usually very small. The important stresses are those due to moments and the above figures indicate that the simple Kellogg expression probably gives a reasonable close estimate of the magnitude of these stresses.

Pressure Margin

Referring to the moments quoted in Table I, the Kellogg expression gives values of local bending stress in the wall of the reactor vessel ranging from 3,050 lb/sq.in. to 2,580 lb/sq.in. for the hot and cold conditions respectively, in the top duct. In the Bradwell pressure vessels the membrane stress due to pressure is 9,800 lb/sq.in., while at the maximum operating temperature of 400°C. the permissible stress in the vessel is 12,000 lb/sq.in. There is thus a margin of 2,200 lb/sq.in. to cover stresses due to all external loadings on the vessel in the region of the outlet nozzles.

Over half this margin is required to cater for a stress of around 1,300 lb/sq.in., due to a moment applied by the variation in the supporting effort of the duct hangers. Thus if the design is carried out strictly in accordance with the British Pressure Vessel Code the permissible local stress at the outlet nozzle due to duct thrust is 900 lb/sq.in. when the vessel

†The flexibility factor k for a bend is defined as the ratio of the flexibility of the bend to that of a straight portion of pipe of the same axial length as the bend. The stress intensification factor J is defined as the ratio of the stress produced in a bend by a given moment to that which would be produced in a straight pipe by the same moment.

is hot. A bending stress of 3,050 lb/sq.in. would mean that the maximum working pressure for the vessel would be reduced from 147 lb/sq.in. to 115 lb/sq.in. The requirements of the ASME Unfired Pressure Vessels Code are membrane stresses due to a pipe moment should be treated as primary stresses while bending stresses should be held to a safe level consistent with experience.

Stresses Too Much

Turning now to the reactor inlet ducts, Table I also shows the terminal moments for these ducts. These moments would lead to local stresses in the reactor vessel wall of about 6,850 lb/sq.in. in the hot condition and 8,750 lb/sq.in. in the cold condition. Additional stresses of these magnitudes could not be tolerated in the wall of a reactor pressure vessel.

To reduce the bending stresses at the reactor outlet nozzles to 900 lb/sq.in. and at the same time overcome the objection to having flexible bends in regions of high radiation it would be necessary to introduce two extra bends in the line of ducting, making in all five bends, four of which would be flexible and one of the usual stiff variety with cascade vanes. Similarly, the layout of the reactor inlet ducts would require three flexible bends and one stiff cascaded bend to provide the necessary flexibility and to comply with shielding requirements.

The importance of keeping to an economic minimum flow pressure loss in the ductwork of a gas-cooled reactor has already been emphasized. In the final design adopted for the Bradwell station the ducts contribute about 1.6 lb/sq.in. to the total circuit pressure drop of 7.6 lb/sq.in. There are five cascaded corners in each circuit and the losses at these corners are estimated to amount to just over 30 per cent. of the total duct loss. This is based on an assumed pressure loss of 25 per cent. of a duct velocity head at each corner. It is thought that this figure is pessimistic and that the actual loss in service will be closer to 15 per cent. of a velocity head.

Reducing Velocity Loss

Bends with a radius ratio of 2 which are not equipped with any form of splitter or turning vanes would give rise to a prohibitively high loss of between 60 per cent. and 80 per cent. of a duct velocity head. This loss can be substantially reduced by the use of a single long-sweep splitter and a further small reduction can be obtained by the use of two suitably proportioned splitters. However, it is doubtful if the loss for a mitred bend can be reduced below the range 30-40 per cent. of a velocity head by these devices.

Assuming a loss of 35 per cent. of a duct velocity head for a mitred bend equipped with splitters and 20 per cent. for a stiff cascaded corner then the pressure drop in a circuit with flexible bends is estimated to be 0.2 lb/sq.in. greater than that calculated for the same system with bellows and stiff cascaded corners. If an extra stiff bend and an extra flexible bend were incorporated in each line of ducting the circuit pressure drop would be increased by 0.6 lb/sq.in. The capitalized value of this increased pressure drop might be as much as £30,000 per circuit.

Systems Compared

To summarize, a design with short-radius flexible bends is attractive because of its fundamental simplicity and low first cost compared with the combination of bellows and rigid single-mitre corners with cascade vanes. A technically satisfactory design for the ductwork associated with a gas-cooled reactor is thought to be possible within the limits of existing knowledge on the behaviour of short-radius bends. It has, however, been demonstrated that this design leads to a more complicated duct layout with a greater number of bends than are required for a duct system which relies on tied expansion bellows to provide flexibility in each line of ducting.

The altered duct layout would appreciably increase the cost of the civil works on the station and this fact, together with the high capitalized value of the charges for the increased pressure drop, led to the rejection of a flexible bend design for Bradwell. It is possible, however, that a case could be made for the use of flexible-mitre bends in a station with a duct arrangement incorporating four or more bends in each line of ducting.

Assuming that the duct thickness is proportional to the bore then the stiffness of a given length of duct is proportional to the fourth power of the diameter. Advantage could be taken of this factor to reduce duct thrusts by using say, two 45 in. bore ducts in parallel instead of one 60 in. bore duct in each heat-exchanger circuit. Flow pressure loss would be about the same in the two designs but the thrust in each of the two 45 in. ducts would be only about one-third of that in the single 60 in. duct. While the large reduction in thrust which can be achieved by the use of small-bore ducts is quite attractive a solution to the duct problems of a nuclear power station on these lines is expensive owing to the duplication of equipment which is involved.

Corrugating Wall Helps

A length of straight pipe can be made considerably more flexible by corrugating its surface. On ducting of the dimensions used at Bradwell a twentyfold increase in flexibility can easily be obtained by rolling or upsetting shallow corrugations in the duct wall. There are, however, a number of serious disadvantages attached to the use of corrugated ducts.

The large axial force due to the internal gas pressure causes a corrugated duct to stretch, and this substantially increases the total movement to be absorbed in the duct system. The gas load also creates bending stresses in the corrugations which are of sufficient magnitude (about 18 ton/sq.in. for the particular type of corrugations examined for Bradwell) to give rise to serious creep in mild steel at 400°C. Finally, the corrugations in the duct wall lead to a substantial increase in the flow pressure loss in the system. For any useful type of corrugation, the pressure loss over a given length is likely to be between eight and ten times that which would occur in smooth ducting of the same bore.

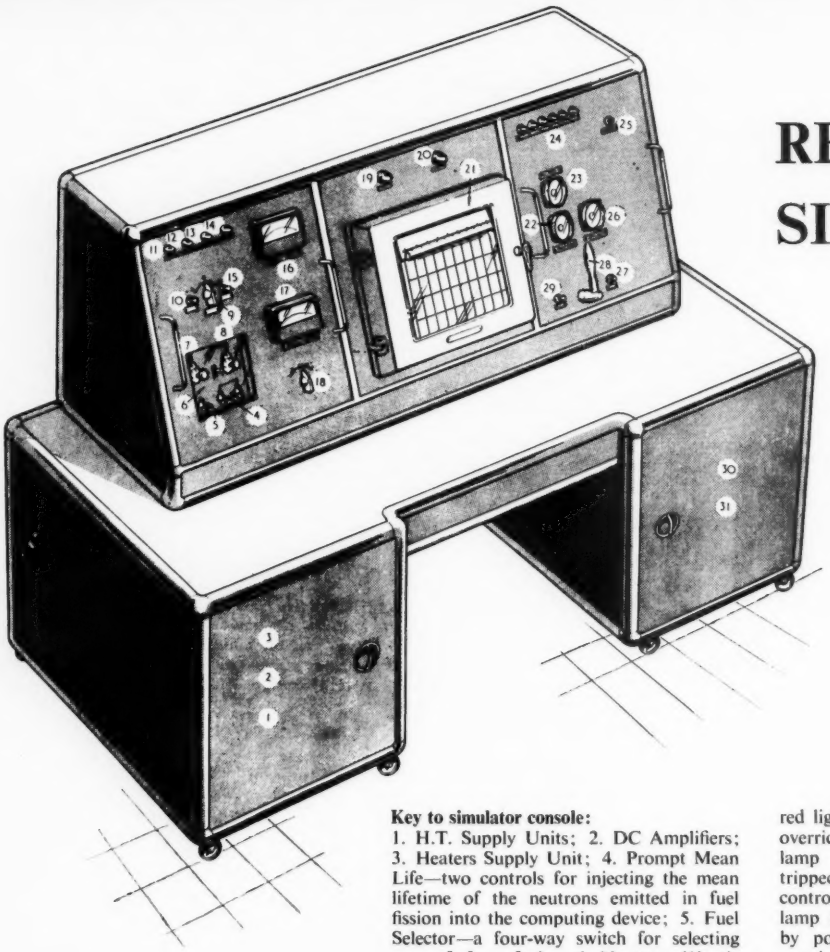
The Best Design

A duct design using tied expansion bellows and large-bore ducts gives the most compact station layout and the lowest circuit flow resistance. The savings on the reduced cost of civil works and of blowing power far outweigh the extra cost of equipping the ducts with expansion joints. The surplus flexibility which usually accompanies a duct design with bellows also gives extra protection to the

(*Continued on page 43*)

REACTOR SIMULATOR

VICKERS Mk I and WORKING CORE MODEL



TO meet the requirements of universities, technical colleges, training establishments and research laboratories where students and staff are taught the nuclear sciences or trained to operate reactors, Vickers-Armstrongs (Aircraft), Ltd., of South Marston, Wilts, have developed the Vickers Reactor Simulator Mk I. They have also introduced a working reactor core model which can be used in conjunction with the simulator or operated, for lecture and demonstration purposes, from a small electro-mechanical control box.

With the simulator it is possible to simulate any thermal or fast fission reactor, running at low power, throughout its power range, up to a level of 100 kW. The five groups of delayed neutrons associated with the fuels uranium-233, 235, or plutonium 239 can be reproduced. An additional hypothetical fuel, U-235/2, enables delayed neutron effects to be demonstrated more clearly by providing just one group of them in addition to the prompt neutron group. The mean life chosen for the delayed group is 12.14 sec. which is the appropriately weighted mean of the five groups used with the fuel U-235.

Thermal reactors using any moderator may be represented, except that the photoneutrons of a heavy water or beryllium reactor are absent. The simulation of fast reactors under normal control conditions can also be achieved.

Safety simulation is obtained by the incorporation of interlocks and trips to provide actual reactor trip and safety responses.

The simulator itself is perfectly safe to operate for all experiments, though it is suggested that operators

(*Continued on page 38*)

Key to simulator console:
1. H.T. Supply Units; 2. DC Amplifiers; 3. Heaters Supply Unit; 4. Prompt Mean Life—two controls for injecting the mean lifetime of the neutrons emitted in fuel fission into the computing device; 5. Fuel Selector—a four-way switch for selecting one of four fuels; 6. Neutron Kinetic Chassis—the electrical network by which neutron kinetic equations are solved; 7. Source $\times 10^{-2}$ watts—simulated source of neutrons which enables a low power level to be maintained in reactor when it is shut down; 8. Excess Reactivity—low capacity key switch for introducing excess reactivity and continuous variable control for selecting its selection; 9. Override—reactor trips may be by-passed using an override selector switch; 10. Reset Trips—push-button control for cancelling any trip condition in the simulator; 11. Trip Warning Override—

(*Continued in next column*)

red light illuminated when trip warning is overridden; 12. Trip Warning Manual—red lamp illuminated when the reactor is tripped by use of push-button shut-down control; 13. Trip Warning "K"—red lamp illuminated when reactor is tripped by power control by rapid increase in reactivity; 14. Trip Warning "P"—red lamp illuminated when reactor is tripped by the power control; 15. Cancel Alarm—bell which sounds when reactor is tripped; 16. Doubling Time Meter—for measuring rate at which reactor power is doubling; 17. Power Output Meter—a logarithmic scale calibrated in watts; 18. Recorder Range Selector—five-way switch; 19. Reactor Tripped Indicator—green lamp illuminated by any trip condition and which remains illuminated until shut-off rods are withdrawn at reactor start-up; 20. Reactor Working Indicator—red light illuminated when shut-off rods are withdrawn at reactor start-up; 21. Recorder with Linear and Logarithmic Scales; 22. Coarse Control Rod Position Indicator—circular dial with range of 0-400 cm and calibrated in 50 cm increments; 23. Fine Control Rod Position Indicator—circular dial linked to coarse control rod indicator with range 0-10 cm and calibrated in 1 cm increments; 24. Warning Lights—Control and Shut-off Rods—two systems each consisting of red, yellow and green lamps to indicate the condition of the control and shut-off rods in the reactor; 25. Shut Down—button press; 26. Shut-off Rods Position Indicator—circular dial indicating fully-in and fully-out positions of rods; 27. Shut-off Rods Out—press button for motoring shut-off rods out of reactor; 28. Control Rods: Dead Man's Handle—for controlling position of the control rods; 29. Release Control Rods—push button which actuates the fall of the control rods into the reactor; 30. Period Meter; 31. L.T. Power Supply Units.

Isotopes in HOLLAND

PRODUCTION AT AMSTERDAM LABORATORIES

by F. R. PAULSEN, BSc, PhD, FRIC, FCS

PHILIPS DUPHAR have their isotopes laboratories in a quiet corner of Amsterdam, near the Ringdijk, and accessible from the city centre by a No. 10 tramcar. At the gate stands a notice forbidding entry, but a little further in, and apparently unaware of the first one, is another notice inviting visitors to report at the office. Such apparent contradiction is perhaps forgivable in an isotope production centre, where the operators are acutely aware of the inherent dangers of their products while at the same time being anxious to be hospitable.

At these laboratories isotopes are produced in a 60 MeV synchrocyclotron. They are sold for use in medicine, industry and research establishments both in the Netherlands and abroad.

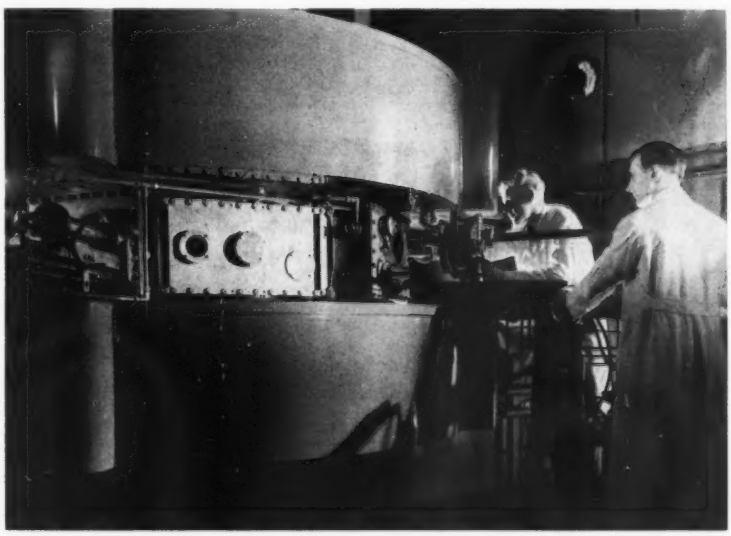
Philips, whose headquarters are at Eindhoven, are, of course, best known in the field of electrical manufacturing. They entered chemical manufacturing by a curious trick of history. Philips, as makers of ultra-violet light equipment, were naturally interested in applications of such devices, and one of the reactions which they studied was the photochemical conversion of cholesterol into vitamin D_3. After a period of research and development on this, Philips decided to join forces with the pharmaceutical firm of Roxane. The combined enterprise, Philips Roxane (it has since become Philips Duphar), eventually came to embrace a vast field of products which included vitamins, hormones, veterinary products, insecticides, plant hormones, weed killers, and more recently, radioisotopes.

First in the Field

Entry into the field of isotopes resulted in the establishment of the radiochemical laboratories in Amsterdam, where the Philips accelerating machine had been constructed. This synchrocyclotron came into action on November 10th, 1948, and since that time has been almost continuously in operation, except for periods of shut-down for improvements. The first shipment of isotopes for commercial use took place in January, 1951, and Philips claims, therefore, to have been the first firm to sell commercially, isotopes. The Amsterdam synchrocyclotron still remains, in spite of developments elsewhere, one of the finest of its kind, by virtue of its high beam current, high yield of products, and great reliability.

There was no guarantee, at the time of Lawrence's conception of the first cyclotron, that the machine would be able to handle production of isotopes. Actually, it proved highly successful. An upper limit, however, was set on the degree of acceleration imparted to such particles as protons, deuterons and α-particles, by the relativistic mass increase. With the development of the synchrocyclotron greater particle energies became possible, but with corresponding decreases in yields.

In the Amsterdam machine, the high beam current, up to at least 20μa-30μa, has been possible through a specially designed ion source. The reliability and efficiency are chiefly the result of the very unconventional design of the acceleration chamber and its components, the efficient vacuum system, and the many safety devices.



The synchrocyclotron used by Philips for isotope production

Cyclotron Design

The synchrocyclotron was designed for a particle orbit of 80 cm. radius, and a pole-piece of 90 cm radius. This necessitated a chamber of 2 m diameter, and a pressure of about 10^{-4} mm of mercury, making the pressure on the top and bottom walls about 30 tons. This difficulty was overcome by making the magnet poles serve as walls, and so providing the maximum utilization of the pole gap. Air-gaps at the two poles, and 7 cm from the face, formed top and bottom chambers which are virtually 7 cm thick, and also produce shimming of the magnetic field.

One original feature of the design is the building up of the chamber from readily-demountable elements. Two octagonal brass rings are separated by eight brass pillars and eight brass plates, the joints having air-tight rubber gaskets, so that total gas leakage is only six litres/week.

The Ion Source

The ion source is a chamber fed with helium at 0.1 mm pressure and operating at 900°C. The ions are passed through a duct, 5 mm, in diameter, into the accelerating chamber. The ion source can be positioned while the cyclotron is in operation. The target is water-cooled, about 0.5 kW of heat being dissipated. The four-stage vacuum pump has an unbaffled pumping speed of 3,500 litres/sec, or 2,200 litres/sec at the chamber.

The control room is separated from the machine by a protecting water layer 3.5 m in thickness. The magnet is energized by a current which is automatically stabilized by a system which incorporates a mirror galvanometer and two photoelectric cells. In the event of a breakdown, the faulty component is automatically isolated, while interlocking systems prevent any manipulative errors.

Modifications

During 1957 a newly-designed electromagnetic deflector system was added to the machine. This made it possible to withdraw from the chamber the accelerated particles. This is the first device of its kind. Formerly, it had been necessary to mount the targets in the accelerating chamber, and although this enabled the maximum use to be made of the beam of accelerated particles, it also reduced the flexibility of the machine for experimental work. Although the new modification meant an inevitable reduction in beam strength, this was easily offset by the increased usefulness of the accelerator as a research tool. The deflector made possible the extraction of the beam, but necessitated considerable change in the building and even a moving of the laboratory.

The Amsterdam synchrocyclotron can accelerate deuterons to 30 MeV and α-particles to 60 MeV, energies which are high enough to produce prolific nuclear reactions, though

Equipment used for the separation of radioactive iodine from the neutron radiated base of tellurium

insufficient to give rise to uncontrollable side reactions with emission of nuclear particles. Deuterons are principally used for the reactions, because of the convenience of the source. Although the reaction ${}^{2}_{1}D + {}^{a}_{n}X = {}^{1}_{1}H + {}^{a+1}_{n}X$ is seldom used, it may sometimes occur, and such a reaction yields the same results as a reaction of the (n:γ) type in a reactor, so that the latter method is the one usually adopted, since larger methods of target materials can be processed for a given expenditure of time and money.

Sodium Isotopes

At 30 MeV, the (d:p) reaction is accompanied by the (d:d,n) reaction, so that when sodium-23 is bombarded with deuterons, the product contains not only the required Na24, but also a small amount of Na22. However, the Na24 free from Na22 and the carrier element, Na23, can be prepared by making use of the (d:p+α) reaction:

$$ {}^{2}_{1}D + {}^{27}_{13}Al = {}^{24}_{11}Na + {}^{1}_{1}H + {}^{4}_{2}He $$

This is only possible, however, if the aluminium target is free from magnesium, since the latter would give rise to Na22.

Table I shows the isotopes prepared on the Philips synchrocyclotron, the yields being based on two-minutes irradiation in the deuteron beam.

At the target, up to 900w may be dissipated as heat, so that it is essential to prevent the melting and evaporation of the target material. This is made even more difficult by the high vacuum. Reduction of the beam strength prevents target damage, while α-particles produce less trouble than deuterons.

Target plates of metal can be silver-soldered to water-cooled copper tubes. If this metal is too brittle, it is soldered to a copper plate and then to a pipe. Sometimes a low-melting element may be fused over the surface of the plate, or alloys may be formed in some cases. The plate may also be coated with molten salts or glassy solids. The form of target which is much used, because of its simplicity, cheapness and versatility is the metal plate clamped between two successive turns of the cooling coil.

Irradiating Neutrons

For short fast-neutron irradiation a vacuum-tight brass tube with a water-cooled thick base is used, the inside open to the air. Deuterons generate neutrons in the base, close to which is the target material, contained in a glass tube. Slow neutrons can be removed by means of a cadmium lining in the brass tube.

For prolonged irradiations with fast neutrons, the specimen is placed in a metal box, closely attached to the box containing the neutron-producing target. Paraffin wax is used for slowing down the neutrons for irradiation purposes.

The preparation of carrier-free radioactive isotopes often involves chemical techniques quite unlike those of the more orthodox analytical procedures, and each isotope has its own particular method. The methods may include crystallization, precipitation, electrolysis, reduction, ion exchange, distillation, colloid formation, co-precipitation, paper chromatography, electrophoresis, extraction, and so on. Surface adsorption often assumes an important role, because of the minute amounts of material handled.

Selective Reduction

Crystallization is often used. Thus, working at correct acidities, it is possible to separate aluminium from sodium by crystallization of the former as chloride or nitrate, but not as sulphate, since an alum is formed. Manganese and cadmium may be separated from their target materials by selective reduction, since the target metals, which are chromium and silver respectively, may be precipitated by zinc or tin.

Solvent Extraction

Cation exchange may be used for the separation of sodium from irradiated magnesium, and rubidium from strontium, for example. Anion exchange serves for the separation of iron from irradiated cobalt, or from manganese. Organic solvent extraction is often useful, and this method finds application, for example, in the use of isopropyl ether for extraction of gallium from copper and cobalt, and of methyl isobutyl ketone for chromium from vanadium, and of amyl alcohol for chromium from vanadium, of chloroform with dithizone for extraction of zinc from copper, amyl alcohol and thiocyanate for separation of cobalt from zinc, and xylene and acetylacetone for partition of iron and cobalt.

Co-Precipitation Common

Electrolysis may be used for separating copper from zinc, cobalt from manganese, etc., while distillation will remove ruthenium and osmium in the form of their tetroxides, or arsenic and germanium as chlorides.

Co-precipitation is one of the commonest techniques employed, and is applied, for example, in the case of calcium or barium with strontium, silver chloride with iodide, arsenic with phosphorus in the form of magnesium ammonium phosphate, and various hydroxides with ferric hydroxide.

After irradiation of lithium metaborate ($LiBO_2$) with deuterons, for

Table I.—Yields of isotopes from Deuteron Bombardments

Isotope	*Target material*	*Reaction*	*μc/μAh*
Be7	$LiBO_2$	d:2n	65
Na22	Mg	d:α	3.2
Na24	Al	d:p,n	2,000
Mg27	Al	d:2p	48,000
P32	FeP	d:p	400
V48	Ti	d:2n	350
Cr51	V	d:2n	185
Mn52	Cr	d:2n	370
Mn55	Fe	d:α	5
Fe55	Mn-Cu	d:2n	6
Fe59	Co	d:2p	1.3
Co56	Fe	d:2n(n)	65
Co60	Zn	d:2α	0.04
Co58	Co	d:p	10
Co60	Cu	d:p,α	0.17
Cu64	Cu	d:p	4,100
Cu64	Zn	d:2p,d:α	1,200
Cu67	Zn	d:2p	1.5
Zn65	Cu	d:2n	6
Ga66	Zn	d:2n	8,000
Ga67	Zn	d:n	410
As74	Ge	d:2n	80
Br82	KBr/K_2CO_3	d:p	235
Rb86	Sr	d:α	20
Sr89	Sr	d:p	5
Y88	Sr	d:2n	55
Cd109	Ag	d:2n	7
In114	Cd	d:2n	16
Au198	Au	d:p	440
Bi206	Pb	d:2n	200

Table II.—Isotopes Generally Available in Holland. Their Source and Saleable Form

Isotope	*Cyclotron produced*	*Pile produced*	*Saleable form*
Be7	Li(d:2n)		$BeCl_2$
Na22	Mg(d:α)		NaCl
Na24	Al(d:p,α)	Na(n,γ)	NaCl
P32		S(n,p)	Na_2HPO_4
S35		Cl(n,p)	H_2SO_4
Ca45		Ca(n,γ)	Ca compounds
V48	Ti(d,2n)		$NaVO_3$
Cr51	V(d,2n)	Cr(n,γ)	Cr, Cr compounds
Mn52	Cr(d,2n)		$MnCl_2$
Mn54	Fe(d,α)		$MnCl_2$
Fe55	Mn(d,2n)		$FeCl_3$
Fe59	Co(d,2p)		$FeCl_3$,Fe citrate
Fe55/59		Fe(n,γ)	Fe compounds
Co56	Fe(d,2n)		$CoCl_2$
Co57	Ni(d,2n)		$CoCl_2$
Co60		Co(n,γ)	Co,Co compounds
Cu64	Zn(d,2p),(d,α)		$CuCl_2$
Cu64	Cu(d,p)	Cu(n,γ)	Cu
Zn65	Cu(d,2n)	Zn(n,γ)	Zn,Zn compounds
Ga66	Zn(d,2n)		Ga citrate
Ga67	Zn(d,n)		Ga citrate
Ga72		Ga(n,γ)	Ga_2O_3
As74	Ge(d,2n)		Arsenates
As76		As(n,γ)	As_2O_3
Cd109	Ag(d,2n)		$CdCl_2$
In114	Cd(d,2n)	In(n,γ)	In,In compounds
I131		Te(n,γ)	NaI
Au198		Au(n,γ)	Colloidal Au, Au on carbon
Bi206	Pb(d,2n)		Bi citrate

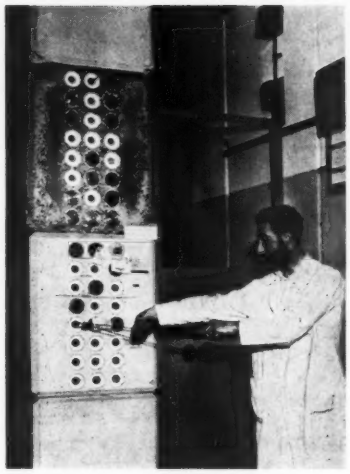
the preparation of beryllium-7, the target is dissolved in water and filtered through sintered glass, which retains the adsorbed colloidal beryllium. Similar methods are used for the adsorption of colloidal radioactive magnesium-27 and bismuth-206 from their targets of aluminium and lead respectively.

Paper chromatography provides an effective and rapid method of separating iron, cobalt and manganese. Electrophoresis is also very suitable.

Isotopes regularly produced by Philips Duphar are listed in Table II. This also lists isotopes made by nuclear reactor methods and which are generally available in the Netherlands. Isotopes can also be prepared to customers' requirements.

Table III.—Applications of Isotopes

Application	*Suitable isotopes*
I. Medical	
(*a*) *Diagnosis*	
1. Thyroid disorders	I131
2. Localization of tumours	I131, P32, Ga66, Ga67, Cu64
3. Blood circulation tests	Na24, Rb86
4. Blood and plasma volume tests	I131, P32, Cr51, Fe59, As74, As76
(*b*) *Therapy*	
1. Thyroid diseases	I131
2. Blood diseases	P32, Na24, Rb86
3. Skin diseases	P32, Sr90, As74, As76
4. Cancers, etc	Co60, Au198, Ga67
(*c*) *Teletherapy*	
1. Irradiation sources	Co60, Ir192, Cs137, etc.
(*d*) *Research*	
1. Toxicology, etc.	Many
2. Drug action and metabolism	Many
II. Plant Physiology, Agriculture, Veterinary, Biochemistry	
1. Photosynthesis	C14
2. Uptake of fertilizers, etc.	P32, K42, Ca45, etc.
3. Trace elements in plants, etc.	Many
4. Soil chemistry, relation of soil to plants	Na22, S35, P32, K42, Ca45, Fe59
5. Phytopharmaceuticals, insecticides	C14, S35, P32, Cl36, Cu64, As74, As76 etc.
6. Metabolism of fats, proteins, carbohydrates	C14
7. Role of vitamins, hormones, enzymes, etc.	C14, P32, etc.
8. Effects of radiations on cells, genetics	Special α-, β- and γ-emitters
III. Chemistry and Physics	
1. Study of organic reactions	C14, S35
2. Study of inorganic reactions	Very many
3. Control of analysis	Many
4. Analysis of complex mixtures by isotope dilution method	Many
5. Diffusion and self-diffusion	Many
6. Investigation of surface active agents	Many
IV. Industry	
1. Estimation of efficiency of filters, for gas, smoke, dust, etc.	I131, Br82, etc.
2. Estimation of volatilization of metals from melts	Many
3. Efficiency of separations	Many
4. Mixing and settling rates	Many
5. Corrosion studies	Many
6. Optimum composition of plating baths and control of electrolysis	Many
7. Lubricants and wear	Fe59, Cr51, etc.
8. Transfer and distribution of inks	Many
9. Self-diffusion of metals	Many
10. Distribution of elements between molten metals and slags	P32, S35, etc.
11. Liquid flow in pipes	Co60
12. Polymerization and vulcanization studies	C14, S35, Cl36, etc.
13. Coatings and dyes on synthetic fibres	Many
14. Thickness of papers, plastics, and other sheets and coatings	Long-life β- and γ-sources
15. Liquid levels in tanks	Co60
16. Specific gravity of liquids	γ- and X-sources
17. Indirect radiography	γ-sources
18. Static elimination on paper, plastics, etc	Long-life X- or γ-sources
19. Starter for discharge tubes	Long-life β-sources



A radioisotope storage cell at the Amsterdam laboratories

Other Isotopes

In addition to the isotopes listed in Table II the following radioactive preparations are regularly produced:—P32 in the form of $POCl_3$ and PCl_3; or as tricresyl phosphate, superphosphate, secondary calcium phosphate, and tertiary calcium phosphate; S35 as heavy metal sulphides, sodium sulphide, crystalline sulphur, KCNS, fuming sulphuric acid; Co60 in the form of needles, tubes, pearls, spheres, wire, and cobalt naphthenate; Br82 as methyl bromide; Sb124 as triphenyl stibine; I131 in the form of iodinated human serum albumin, and as di-iodofluorescein; Au198 as gold seeds, 0.8 mm in diameter, and gold grains 0.8 mm in diameter and length 2.5 mm. There are also available radiographic sources of Co60 and Ir192, in sealed aluminium holders, and static eliminators and γ-spectrography calibration sources.

Philips Duphar Isotope laboratories issue a series of technical bulletins in which information is given to potential customers. One of these bulletins gives a broad survey of the applicability of radioactive isotopes, and since this list is of considerable value, it is given in an abbreviated form in Table III.

The author thanks Philips Duphar for their courtesy in allowing him to visit their Isotopes Establishment, and for enabling him to gain the information on which this article is based.

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Training N-Scientists in Australia

WORK OF UNIVERSITY OF NEW SOUTH WALES MASTER OF TECHNOLOGY DEGREE COURSE

*by L. C. Woods, DSc, PhD, BE, MA**

ON May 10th, 1954, it was resolved by the Council of the University of New South Wales, Australia, that a Research Institute of Nuclear Engineering be created within the university under the control of the Council to develop and encourage research in the various fields of nuclear engineering. Among the aims of this Institute the resolution listed were:—

(i) to encourage and develop within the university research and post-graduate training of engineers and applied scientist in fields covered by the term " nuclear engineering ";

(ii) to provide assistance and information to industry regarding the engineering and applied science aspects of an atomic power programme in Australia, and to help in developing industrial readiness for such a situation; and

(iii) to organize periodic post-graduate courses and lectures on various aspects of nuclear engineering.

The Institute was created, and a committee was established comprising the professors of those subjects having relevance to nuclear engineering, namely the professors of physics, chemistry, mechanical, electrical, chemical and mining engineering and metallurgy.

Prof. Baxter, Chairman

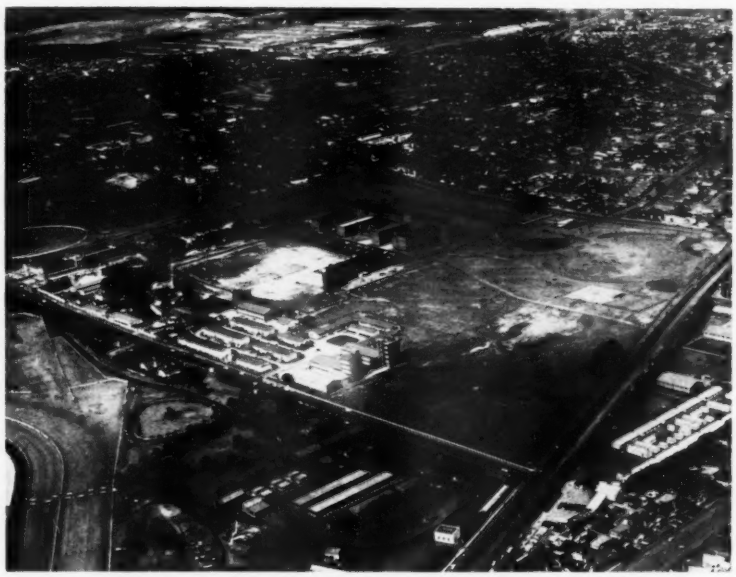
The committee of the Institute, which is under the chairmanship of the vice-chancellor, Professor J. P. Baxter, who is also chairman of the Australian Atomic Energy Commission, meets several times a year, principally to consider the various research and teaching programmes under way or proposed in the constituent schools. In this article only the lecture and laboratory courses fostered and planned by the Institute are discussed.

The Institute has, however, encouraged research, mainly through the granting of funds, in almost all the schools represented on the committee. As a result a steadily increasing programme of research is emerging.

At the Beginning

One of the first ventures of the Institute was a two-day Symposium on Atomic Power, the lectures being aimed at a general scientific audience. That was in 1954. Two years later a course of 15 lectures was given to engineering and scientific graduates in industry who wanted an introduction to the field of nuclear engineering. The course proved very popular and was repeated in 1959. More specialized courses given in 1956-57 were on (i) reactor materials (20hr in 1957), (ii) radiation shielding (12hr in 1957), (iii) advanced reactor theory (12 hr in 1957), and on (iv) radioisotopes (15 hr in 1956, repeated several times). A full-time two week laboratory course in isotope techniques was also provided.

In 1958 the university decided to introduce an annual part-time course in nuclear engineering extending over one year. This course was designed with two objects in mind. Firstly it was to provide a final year elective subject for BE students in mechanical engineering. Secondly it was to be an introductory professional course in reactor science



Aerial view of the site of the University of New South Wales taken in 1957

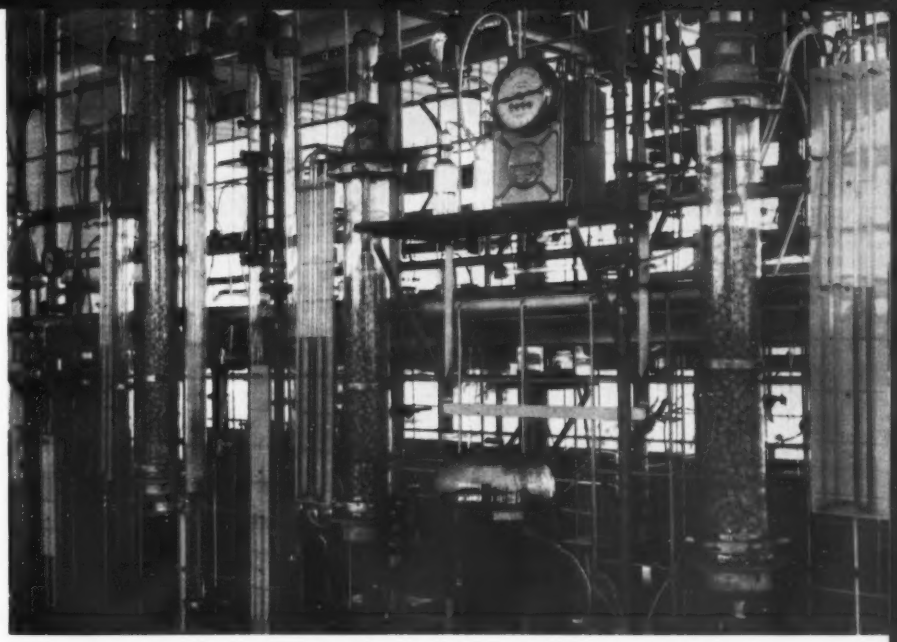
*Nuffield Research Professor in Mechanical Engineering, University of New South Wales, and NUCLEAR ENERGY International Editor.

and technology for graduates in industry and Government research.

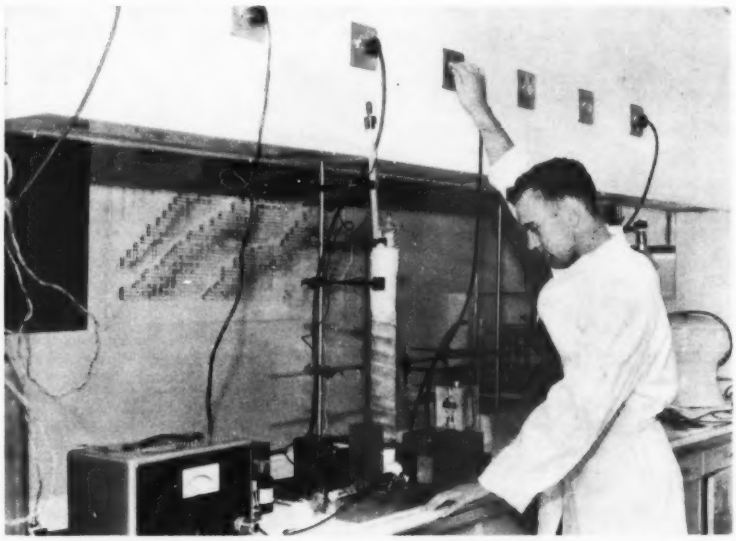
The course consists of 50 hr of lectures covering physics, reactor theory, chemical and metallurgical aspects, shielding, reactor types and technology. There are also 24 hr of laboratory work.

The course is given in the evenings and has proved very popular with about 20 students in both 1958 and 1959. Success in a 3 hr examination at the end of the course qualifies post-graduates for a certificate and undergraduates for a credit towards their BE degree.

There is no intention that nuclear engineering should intrude further into the undergraduate course. It is held that this subject is best developed as a post-graduate study.



Solvent extraction equipment for the extraction of uranium in solution. One of the pieces of equipment in the laboratories of the School of Metallurgy, the University of New South Wales



The radiochemical laboratory in the nuclear and radiation chemistry department of the University of New South Wales. It is the first laboratory in an Australian University to be specially designed for radiochemistry

All the same, it is felt that all engineering undergraduates, whatever their ultimate aim, should be exposed to lectures in nuclear engineering, whether given as a special course as provided by the University of New South Wales or as a set of lectures within the final year of applied thermodynamics.

Weakness Overcome

One of the weaknesses of the degree structure in Commonwealth universities (as distinct from universities in U.S.A.) is that the Master's degree is almost always awarded for research work. However, the Bachelor's degree is very quickly becoming a quite inadequate stopping point for those who wish to leave university with some specialized up-to-date knowledge of an advanced field without undertaking research in it (for which he is not properly prepared in any case). The University of New South Wales has sought to fill this gap by introducing a Master of Technology degree, which consists of about 70 per cent. to 80 per cent. of formal course work, the rest being spent on a minor thesis.

In 1960 the university will offer an MTech degree in Nuclear Engineering. The course for this will extend full-time over one year and will involve the students in about 30 hr "contact" time (lectures, laboratories, tutorials and supervised study periods) per week during the first two terms and somewhat lighter load in the final term. In this final term the student is required to work on a project and present his findings in a minor thesis. The course will be open to all engineering graduates.

N-Study Balanced

The first term of the course will be devoted to a broad study of all branches of nuclear engineering. In the second term the students will concentrate on the *engineering* aspects of the subject, and in view of their undergraduate training the material presented to them will be genuinely post-graduate study in such subjects as control engineering, heat transfer, and thermal stresses. The application to reactor design and engineering of these subjects will, of course, be stressed, but not to the point where the course contains an excessive amount of nuclear technology—the engineering *science* aspect will remain dominant. This is important in view of the rate of change of the subject and the fact that it may be many years before graduates who remain in Australia can use their technical knowledge in the reactor field.

Subjects Embraced

The subjects covered in the course will be: physics, mathematics, reactor theory, reactor control, chemical and metallurgical aspects, shielding and health physics, reactor engineering

and technology (including reactor design, heat transfer and fluid mechanics), thermonuclear power, power-station engineering, and radioisotope applications. The main emphasis of the course will be on reactor theory and reactor engineering and technology, and lectures on these subjects will comprise more than half the total number of lecture hours.

As already mentioned the third term will be spent principally on a thesis project of a design or research nature. It is also planned that in this term the students will spend some time in the laboratories of the Australian Atomic Energy Commission at Lucas Heights, some 20 miles south of Sydney. There they will obtain practical experience on sub-critical and zero-energy assemblies.

Advantages of N.S.W.

To make these and other facilities available to all Australian universities there has recently been established the Australian Institute of Nuclear Science and Engineering to act as a liaison body between the universities and the Atomic Energy Commission.

It seems probable that no other Australian university will develop nuclear engineering courses to the extent to which it is planned in the University of New South Wales. This particular university has certain important features which make it suitable as a nuclear engineering centre. First of all, it has a relatively large number of staff members with experience in the fields of nuclear engineering and science. Secondly, it is close to the Lucas Heights Laboratories. In addition, the university also has well-developed courses and laboratories in the related fields of chemical engineering, metallurgy and radio-chemistry, while the School of Mechanical Engineering with a staff of 40 must be one of the largest in the Commonwealth.

Harwell Man in Charge

The MTech degree course, the structure of which has been largely designed by the author, will be controlled in a general way by the Institute of Nuclear Engineering and the Faculty of Engineering. The executive officer in charge of the course will be Dr. A. Keane, an applied mathematician who spent 1958 working on reactor theory problems at the Atomic Energy Research Establishment, Harwell. Dr. Keane maintains a close liaison with the Reactor Physics group at Lucas Heights. At least nine other members of the university's staff have had research and practical experience overseas in the nuclear energy field. With a lapse of time this figure should increase considerably.

The Australian Atomic Energy Commission provide a number of post-graduate scholarships for research work into nuclear energy and related fields and so far the University of New South Wales has been awarded 20 of these. Research grants from the Commission are also valuable in promoting research in the nuclear energy field.

In view of the expense of buying, housing and maintaining a teaching reactor, and also of the nearness of the facilities at Lucas Heights, it has been agreed that for the time being at least the university will not install one. A sub-critical assembly may be built in the future, but it is expected that for the first few years the assemblies being built at Lucas Heights will be sufficiently available to our students to provide satisfactory training. Laboratory experience in nucleonics, measurement techniques, shielding, automatic control, use of radioisotopes, and similar topics not requiring a nuclear reactor, will be provided within the university's laboratories. The degree does not and cannot aim to produce reactor operators; the emphasis must be on basic principles with the practical experience being obtained in the nuclear energy industry or in research establishments.

REACTOR SIMULATOR

(*Continued from page 26*)

should exercise the same care and precautions as they would if controlling a reactor.

The core model represents the cross-section of a typical, graphite moderated nuclear reactor and gives an illuminated pictorial representation of the events taking place within the core. Shut-off rods, control rods and fuel elements are represented by coloured strip lighting. The control and shut-off rods are movable and operate in synchronism with the corresponding controls and indicators on either the simulator or the model control console.

The lighting representing the fuel elements is variable in intensity so that when the reactor is at full power it glows brightly and as the reactor is shut down fades. It is regulated by a signal from the simulator, or from the model control console.

The Vickers Reactor Simulator Mk I and (*on the right*) the Vickers core model which can be used either in conjunction with the simulator or a separate model control console

PEOPLE... in the NUCLEAR NEWS

DR. MOSTAFA B. TALAAT, an Egyptian-born engineer, has joined the nuclear division of The Martin Co., Baltimore, U.S.A. He will direct all research and development work on energy conversion, concentrating particularly on thermoelectric, thermionic and magneto-hydrodynamic systems. Thirty five years old, Dr. Talaat, who was born in Cairo went to the U.S.A. shortly after receiving his bachelor of science degree in electrical engineering, with honours, from Cairo University in 1946. He earned his master's degree and doctorate in electrical engineering from the University of Pennsylvania in 1947 and 1951, respectively. Before receiving his doctorate he spent two years teaching electronics at the Massachusetts Institute of Technology, and later he taught briefly at the University of Pennsylvania before entering private industry. At the

Dr. M. B. Talaat

Elliott division of the Carrier Corporation and later at the Carrier Research Centre, Dr. Talaat carried out a number of research and development programmes in energy conversion. He developed the design concept of a 5 kW thermoelectric generator and supervised the project for the U.S. Navy through all phases of analysis and component testing. Dr. Talaat holds two patents on thermoelectric generators and one on the cooling of electric machinery, and he has published a dozen papers and technical discussions in the *Transactions of the American Institute of Electrical Engineers*. In 1955, 1957 and 1958, his AIEE papers were singled out for special awards.

An Argonne National Laboratory physicist, **Dr. STEFAN G. KAUFMANN,** has accepted a one-year appointment to the French Centre D'Etudes Nucléaires (Centre of Nuclear Studies) at Saclay, near Paris. The appointment has been made as part of an informal exchange programme between Argonne and Saclay under which personnel from the two laboratories spend approximately one year abroad in nuclear reactor engineering and physics studies. At Saclay Dr. Kaufmann will participate in unclassified studies of "fast" nuclear reactor systems. A member of the Argonne reactor engineering division, he has participated in several experimental studies of fast reactors utilizing the Experimental Breeder Reactor I (EBRI) operated by Argonne at the National Reactor Testing Station in Idaho. Born in Berlin, Germany, in 1921, Dr. Kaufmann emigrated to the United States to escape the Nazi regime in 1940. He attended universities in Germany and The Netherlands, is a graduate of Manchester College, North Manchester, Indiana, and received his PhD degree from the University of Wisconsin, Madison. He has been a member of the Argonne reactor engineering division since 1951.

The European company for the Chemical Processing of Irradiated Fuels (EUROCHEMIC) have appointed **DR. ERICH POHLAND,** of the German Bundesministerium fur Atomkernenergie (German Federal Ministry of Atomic Energy), as general manager of the company. Dr. Pohland was last July elected chairman of the board of directors. **DR. R. ROMETSCH,** formerly of the Swiss "CIBA" company in Basle, has been appointed research director of Eurochemic.

MR. J. E. SMITH, of Richardsons Westgarth & Co., Ltd., takes up the position on January 1st, 1960, of managing director of the National Gas & Oil Engine Co., Ltd. He will also become a member of the board of Hawker Siddeley Industries Ltd. Mr. Smith who is 45 years old, is at present a director of Richardsons Westgarth and managing director of their subsidiary, The North Eastern Marine Engineering Co. He has been associated with the Richardsons Westgarth group for practically the whole of his career.

The nuclear division of The Martin Co., Baltimore, U.S.A., have awarded $1,000 to two of their engineers, **MR. HAROLD N. BARR** and **MR. DONALD H. PETERSON,** for developing a strikingly simple but promising solution to abrasion problems in an advanced nuclear reactor system Martin is developing. The system, called "LFBR" (Liquid Fluidized Bed Reactor), will use small pellets of fissionable fuel immersed in water inside a cylinder. Because a power-producing chain reaction can take place only when the pellets are separated from one another by a certain amount of the liquid, the reactor will be turned on simply by forcing more water up through a perforated plate on which the pellets rest. A major problem in such an arrangement is that the pellets gradually become worn away as they tumble over and over one another. But Barr and Peterson suggested adding powdered graphite to the water. Abrasion dropped to less than 20 per cent. of what it had been, and there is a possibility that the graphite will also improve the heat transfer characteristics of the system. Martin-Nuclear have also made five other company patent awards, totalling $375. **MR. WILLIAM CORLISS** has received $250 for work on a conceptual design of a 100 kW to 1,000 kW nuclear reactor for use in space. **MR. JOHN L. SAUER** and **Mr. CLAUDE C. CARDWELL** have been awarded $25 each for a device to indicate the position of reactor "control rods" inside a closed container. **MR. WILLIAM F. BEUTEL** has received $50 for the design of a flexible fuel bundle which may facilitate a system of continuous refuel ing in nuclear reactors, while **MR. JOHN I. McNEIL** has been awarded $25 for development of a reliable power supply that is less expensive and offers more precise control than the one now in use on control rod actuators for Martin reactors.

Shortly after establishing a Scottish office, West Instrument have now extended their sales and service coverage in the United Kingdom by opening a Newcastle office. Appointed as manager of the new office is **MR. W. I. McNALL,** BSc(Hons). Formerly a research physicist at United Glass Bottle Manufacturers, Mr. McNall has worked with James A. Joblings ("Pyrex") since 1956 and was assistant factory manager before taking up his new appointment. He has done considerable work on the control of temperature, flow, etc., and has visited the United States to study forming machinery.

MR. TIBOR HAAS, Dipl Ing, AMIMechE, AFRAeE, has been appointed head of the design section in the newly formed members' service department of the British Welding Research Association, Abington, Cambridgeshire. Mr. Haas, who was educated at Prague University, has had many years' experience in mechanical engineering, light weight engineering design and heavy engineering. Following a period as industrial consultant on contracts throughout Europe he joined the Bristol Aircraft Co., of Filton where, for six years, he held the position of head of the fatigue department.

MR. C. H. FLURSCHEIM, BA, MIEE, MemAIEE, a director and the chief electrical engineer of Metropolitan-Vickers Electrical Co., Ltd., has been co-opted to serve on the Council of the British Welding Research Association. Mr. Flurscheim began his career in 1927 as college apprentice with Switchgear Engineering Co., Ltd., and in 1936 was given control of the company's high voltage division. He was appointed chief engineer following work on the development of electro-mechanical undercarriages and miniature circuit breakers for aircraft during the war. He became chief electrical engineer of Metropolitan-Vickers in 1957 and a director in 1958.

STANFORD University, California, has long held a reputation for pioneer work on linear accelerators, and their 220 ft machine can produce electrons with energies up to 1,050 MeV. One could well imagine that to increase this machine to a length of 2,200 ft would have been no mean feat, but this would have been only to invite competition. So, in order to keep its lead safe, Stanford is to build a linac two miles long, driven into a mountain at Palo Alto. This surely should leave Stanford's pre-eminence unchallenged for a long time to come. The new project, which is to take six years and to cost over $100m., will enable the scientists to produce electrons with energies up to 15 BeV.

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Talking of accelerators, I am reminded of some of the reactions to the CERN conference on accelerators, held in September, 1959. J. B. Adams, Director of CERN's P.S. Division, said that the conference has brought forward no new ideas, but that contributions were more valuable than those of the 1956 meeting. This view was shared by Prof. W. K. M. Panotsky of Stanford, U.S.A., and by Wang Kan-Chang, of Dubna. There can be no doubt, though, that these enormous conferences are very expensive, and drag away the delegates from valuable work from which they can be spared only with difficulty. Nevertheless, and I assert this even in the face of W. Jentschke, of Hamburg, who considered that these conferences are being held too frequently, no effort should be spared to bring world scientists together again and again. Not only is there a very valuable exchange of technological ideas, and an opportunity to see what the other man is doing about things, but, and perhaps this is an even more important aspect, there is the fostering of mutual trust and understanding which are so sadly missing from the political meetings. It would be too much to say, perhaps, that the peace of the world is in the hands of scientists, but at least they are doing rather more than their share to dispel ill-feelings between the nations.

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The bringing together of 31 major firms into the French combines France-Atome and Indatom resulted in a formidable array of nuclear technical experience to make its début in the international market. It would be surprising if, in the field of research reactors, nuclear laboratories, and fuel elements, this frontal attack should not succeed, even in face of British and American competition.

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And that reminds me of the many collaborations springing up between British and other firms in various nuclear markets. There was a great deal of ebullient optimism when the British firm of Humphreys and Glasgow came to an agreement with A.M.F. for the provision of the "tennis-court" size nuclear power station for large industries or underdeveloped countries. However, there has been an almost incomprehensible reluctance on the part of would-be purchasers to take the plunge. Can it be that each was awaiting the initiative to be taken by another, and

'NUCLEARIST' *writes . . .*

to see how he got on with the new power plant before himself taking the matter in hand? Now we hear of Humphreys and Glasgow teaming up with the American Babcock and Wilcox to supply nuclear power plants in the 17.5 MW to 30 MW range. Is this a case of coming back for a second knock on the jaw, or is there this time something new to appeal to those who were not convinced before? This new combination will be worth watching, for there is more than prestige at stake.

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At the Wolgang works of Degussa, near Hanau, Germany, the first European electronic beam melting furnace has come into being. Under a voltage of 12,000, electrons are shot from a tungsten electrode and reach a speed of 60,000 km/sec, a velocity which makes even these small particles highly energetic. This energy, directed on to a material, will quickly melt the latter. This method is being used for the melting and refining of metals such as tungsten, tantalum, molybdenum and niobium, which are normally highly refractory. The melting is done under pressures of 10^{-5} torr., and impurities are rigidly excluded. This new technique has a great future, and the number of furnaces making use of this idea will certainly expand rapidly.

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Fusion of metals reminds me of the fusion of nuclei, and of ZETA. The news that the UKAEA hopes to develop a 175-acre site at Culham, Oxfordshire, for work on thermonuclear fusion need come as no surprise. When the big burst of enthusiasm over ZETA came, it was generally felt that the timing, influenced by American commitments, was poorly judged. ZETA could have been publicized earlier, when the British lead would have been made even clearer. Or it could have been delayed until there was more assurance among the Harwell scientists that ZETA was, in fact, capable of producing a nuclear fusion. Since that somewhat damp squib, it has been well known that the ZETA team had plans for stepping up the size of the ZETA project. The size of the new installation, together with the need for new approaches to the question of nuclear fusion, made it imperative that new premises be found, and a separate establishment seemed to be called for. Now it looks as if Culham is to be the answer.

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With nuclear power and atomic weapons all too much in the public eye, the medical applications of the atom are too easily overlooked. It is encouraging, then, to know that the biomedical research institute of the U.S. Army's Walter Reed Hospital, in Washington, is to be enlarged. Its reactor is at present the only one in the U.S.A. to be entirely devoted to medical work, and the centre has facilities for isotope production, therapy, diagnosis, and research. There is a special room in which neutron irradiation can be carried out with freedom from gamma rays. It is somewhat irritating to read of these fine facilities being provided when in Britain there has been singularly little development of hospitals since the last war.

NUCLEAR NEWS

- **Canadian N-Expansion Planned** *(This page)*
- **Radiation Bill** *(Page 42)*
- **N-Briefs** *(Page 44)*

ATOMIC ENERGY OF CANADA Ltd., are to build a new nuclear energy research and development centre in Manitoba, according to Canadian Minister of Trade and Commerce, Gordon Churchill. Canada's only other nuclear research centre is the Chalk River establishment of AECL on the Ottawa River, about 150 miles west-north-west of Ottawa. The government-owned company, however, has a Nuclear Power Plant Division in Toronto and a Commercial Products Division in Ottawa. The directors and management of Atomic Energy of Canada Ltd., have recommended to the Federal Government that, to permit the Chalk River centre to operate at its maximum efficiency, the centre should not continue to expand. Among the major facilities at Chalk River are four research reactors including the NRX and NRU reactors, particle accelerators and chemical and metallurgical plants. The number of workers nears 2,500. Over the next 25 years the research and development effort in the field of nuclear energy must expand if Canada is to maintain its position as one of the leading atomic energy nations. During this period several new major research and development facilities will have to be built. Preliminary discussions have been held with the Manitoba Government and it is expected that site surveys will be carried out in Manitoba within the next few months, and a site selected by early 1960. The construction of buildings and laboratories, and the installation of equipment and technical services at the site, will start with the next major project to be undertaken by AEC in the research and development field. This may be an organic-cooled, natural uranium-fuelled, heavy water-moderated power reactor experiment in about two years' time.

Data Collaboration

A EUROPEAN-AMERICAN Nuclear Data Committee has been set up by the European Nuclear Energy Agency, in agreement with Euratom, the United States of America and Canada, to assure collaboration among OEEC member and associate countries in the measurement of nuclear properties. The Committee will be primarily concerned with nuclear cross-sections measurements and other basic data essential for the technical development of nuclear energy. The Committee is to consist of 13 experts from the United States, Canada, the United Kingdom, the Euratom and other OEEC countries. Its operations will be in accordance with existing bilateral agreements.

Underground Tests

THE Atomic Energy Authority are to carry out a series of conventional explosive tests in a lead mine at Glenridding, Westmorland, for the purpose of providing information on the detectability of underground nuclear explosions. They will supplement the tests being undertaken in an old tin mine at Callington, Cornwall. Up to 5 tons of explosives will be detonated at a time at Greenside and 1,000 ft below ground level. Precautions will be taken to prevent surface disturbance or damage.

INSTITUTION OF NUCLEAR ENGINEERS

A Finance and General Purposes Committee of the Institution of Nuclear Engineers has been formed under the chairmanship of Mr. F. L. Coombs, LLB, AMIEE. Among its responsibilities will be the consideration of applications for membership to the Institution and one of its first tasks will be the formulation of examinations for applicants whom they consider do not possess the necessary qualifications for membership. Members of any of the senior professional engineering Institutions and/or holders of University degrees will normally qualify for membership without examination.

Reactor Centrum Nederland

Aerial view of the research centre of the Dutch nuclear research association, Reactor Centrum Nederland, at Petten, near Amsterdam, with the 20 MW research reactor supplied by ACF Industries, of New York, nearly completed

More Core Chores

WESTINGHOUSE Electric International Co., is expanding its nuclear core manufacturing laboratories in order to provide additional development and production facilities for reactor fuel elements and core components. An additional facility is nearing completion which will house a newly formed group—the Nuclear Components Development Laboratory. This will be available to industrial and government customers for evaluation programmes and to conduct pilot and full production of nuclear fuels and materials. Initial work will be directed at improving uranium oxide fuel element fabrication and uranium alloy fuels clad in such materials as zirconium, aluminium, niobium, molybdenum and stainless steel.

S.I.M.A. may hold Moscow Show

Members of the Scientific Instrument Manufacturers' Association of Great Britain who recently visited Moscow to discuss the possibilities of holding an exhibition of British equipment in the Russian capital this summer. (*Left to right*) **Mr. H. D. Binyon, of Solartron, Mr. L. A. Woodhead, of Cossor Instruments and SIMA president, Mr. C. F. Hamill, of Hilger and Watts, and Mr. K. A. McDonald, of Unicam**

NUCLEAR NEWS

Radiation Bill

IN order to ensure that the widening use of radioactive materials does not expose the public to dangerous amounts of radioactivity the Government has decided to extend and unify the controls over the discharge of radioactive wastes. Previously, and apart from the arrangements applying to the Atomic Energy Authority, risks to public health have been avoided principally through co-operative arrangements between central and local government. On the advice of an expert panel, however, the Government proposes to revise the system. The recently introduced Radioactive Substances Bill, provides that: (1) Temporary controls (which bring under the control of the Minister of Housing and Local Government and the Minister of Agriculture, Fisheries and Food—in Scotland, the Secretary of State—any discharge of radioactive wastes by the UKAEA and other licensed nuclear installations) will be made permanent; (2) Other users of radioactive materials will be obliged to register their premises with the appropriate Minister (in England and Wales the Minister of Housing and Local Government, and in Scotland, the Secretary of State); (3) No disposal of radioactive wastes will be permitted except on an authorization from the appropriate Minister or Ministers; and (4) The Minister of Housing and Local Government and the Secretary of State for Scotland will, in addition, have power to arrange a national disposal service to handle wastes which cannot safely be dealt with in the areas in which they originate.

German Neutron Plant

FOR use with their research reactor at Garching, near Munich, the Institute of Applied Physics of the Munich Technical University has commissioned a neutron diffraction plant designed by the Institute staff in co-operation with Maschinenfabrik Augsburg-Nurnberg. Of a standard design the plant can be adapted to suit any type of reactor and to meet specific requirements. Consideration has been given to ensuring that the widest possible range of application is possible and it is for this reason that it has been equipped with a novel drive permitting automatic scanning of the neutrons scattered by the specimen in very small steps (up to 5 arc/min). The counting tube moves through an angle of 130° within a pre-set time limit which may be extended to as much as one month. Neutrons of equal length are produced by diffraction in a crystal arranged on the centre line of a rotary shield.

U.K.A.E.A. Control Course

THE third Reactor School course on the Control and Instrumentation of Reactors will take place from February 1st to 12th, 1960, inclusive, and will be open to British and overseas students. It will be held at Durley Hall, Bournemouth, Hampshire. The course is primarily intended for those who have a direct interest in the control and instrumentation of nuclear reactors, and it will be assumed that participants have some knowledge of the basic principles of these subjects. The topics to be treated will include:—elementary reactor physics; revision of elementary reactor kinetics, control and instrumentation; automatic control of reactors and nuclear power plants; application of computors; reactor transfer functions and function analysers; neutron counting equipment; neutron flux detectors; neutron flux scanning; radiation detectors and their siting in reactors; reactor safety circuits; conventional instrumentation; use of transistors in reactor instrumentation; burst slug detection; design of control mechanisms; spatial instabilities in reactors; date reduction problem on large reactors. In addition to the lectures there will be visits to zero energy and high flux research reactors and other relevant parts of the Harwell Establishment. There will also be a visit to the Atomic Energy Establishment, Winfrith. The fee for the course will be 50 guineas, exclusive of accommodation, and application forms, available from the Reactor School, must be returned by 11th December, 1959, to:—The Principal, Reactor School, Atomic Energy Research Establishment, Harwell, Didcot. Berkshire. The fourth course on the Control and Instrumentation of Reactors will take place from May 23rd to June 3rd, 1960, inclusive, also to be held at Durley Hall, Bournemouth.

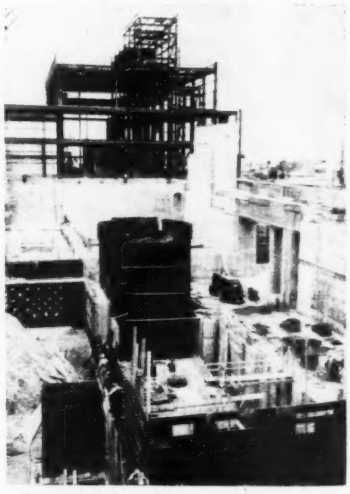
A.G.R. Data Exchange

THE United States Atomic Energy Commission and the United Kingdom Atomic Energy Authority have signed a five-year agreement to exchange technical information on advanced gas-cooled reactors. The exchange will be carried out under the terms of the U.S.-U.K. agreement for co-operation in the civil uses of atomic energy which has been in effect since 1955. Data will be exchanged on development, design, construction and operation, as well as on related research and development, of the advanced gas-cooled reactors being built at Windscale, England, and on the U.S. experimental reactor project of this type at the Oak Ridge National Laboratory.

Correction

In our November 1959 issue, the name of the author of "The Power of a Heavy Water Reactor during an Emergency Shutdown" was incorrectly given as I. M. El-Ibiary. It should have been M. Y. El-Ibiary, BSc, PhD. We apologize to the author for any inconvenience this might have caused.

In Nebraska



The 75 MW sodium graphite reactor power plant under construction at Hallam, Nebraska, U.S.A. The plant is scheduled for completion in 1962. The reactor is being supplied by Atomics International

Weak Activity Test

A LEADING member of the electronics division of the United Kingdom Atomic Energy Research Establishment, Harwell, has invented a device which permits very quick testing for weak radioactive contamination, such as might be found on the hands of personnel working with radioactive materials. The invention is based on the observation that, although the random nature of individual radioactive disintegrations requires that very many be counted if a statistically reliable measurement of radioactivity is needed, in cases where it is only required to find out whether or not the activity exceeds a set level, it is—in principle—only necessary to carry out a long count when the activity is close to this level. Sources which are much stronger or much weaker can—in principle—be disposed of by making a far less accurate measurement in a much shorter time. This can be achieved by applying the principle of sequential sampling, a technique used in production control. The method is to count the number of radioactive disintegrations observed since the beginning of the counting period and to subtract continuously the number which would have been observed had the activity been exactly equal to the set level. The difference between these two numbers grows continuously and when it has attained a predetermined value (positive or negative) the test is ended. The sign of the difference then shows whether the activity is greater or less than the set level. The more the activity differs from the set level the faster this difference is accumulated and the shorter is the time taken to complete the test. The electronic device which performs this function is called a difference integrator. It may take several forms. In one, each pulse due to a disintegration causes the charge on a capacitor to be increased by a known amount. At the same time charge is being continuously withdrawn from the capacitor at a rate corresponding to the set level of activity. When the net charge on the capacitor reaches a predetermined positive or negative value a "high" or "low" indicator operates and the test is ended. Another version uses a reversible pulse-counting device driven in one direction by the unknown pulses and in the other by pulses from a standard pulse source.

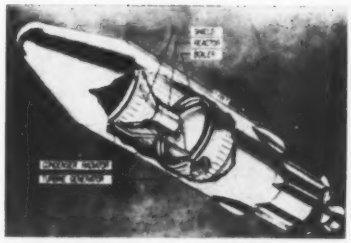
System Engineering

DE HAVILLAND PROPELLERS Ltd., who have produced the Firestreak infra-red guided missile carried as standard armament by the latest R.A.F. and Naval fighter aircraft, and who are prime contractors for the British ballistic missile, Blue Streak, have formed a new group to apply their experience in system engineering to the development of equipment for the automatic control of industrial processes and manufacture of all kinds. The group has a great fund of practical knowledge to draw upon from within the company in such diverse and complex fields as advanced electronics, measuring techniques, dynamics analysis, hydraulic and pneumatic engineering and servo systems. The group will place particular emphasis on the design of integrated systems, and here the comparatively new techniques of system engineering will be used, backed by digital computer investigations where necessary, to produce the optimum design at any level of complexity. There are now many industries which can make use of automation and the system engineering group is already holding discussions with the engineering, oil refining, chemical, food, sugar, brewing and paper industries, and many others. The system engineering group will be located at Hatfield in its own premises adjacent to the propeller company's head office. The technical team will consist of Mr. R. J. Perdue, Mr. M. James and Mr. R. A. Rubinstein.

Submarine Order

ALCO PRODUCTS Inc. have received an order for 10 stainless steel pressurizers for the U.S. Navy's submarine nuclear-propulsion programme. The pressurizers will be built for Westinghouse Electric Corporation for use in nuclear-powered submarines of the *Skipjack* class. Westinghouse designed and developed the nuclear reactor for the *Skipjack* under the direction of, and in technical co-operation with, the Naval Reactors Branch, U.S. Atomic Energy Commission. Delivery of the order by ALCO is expected to begin in February, 1960 and be completed during the year. The fabrication work will be done at ALCO's thermal products division plant in Dunkirk, New York.

SNAP-II



(*Above*) **The 220 lb enriched uranium fuelled sodium cooled reactor SNAP-II, developed by Atomics International as it would look like inside a space satellite. The prototype of this reactor (*below*) was recently successfully operated at full design power and temperature. A smaller satellite reactor, SNAP-III, using polonium as fuel, was successfully demonstrated last January by the Martin Co.**

LARGE GAS DUCTS

(*Continued from page 32*)

reactor vessel against unforeseen thrusts caused by errors in the erection of the ductwork, differential settlement of the station foundations and maloperation of the plant. On the other hand bellows are specialized pieces of equipment. They are generally highly stressed and, unless designed with care, can be a serious source of weakness in the pressure circuit.

Expansion bellows are used in the ducts of all British gas-cooled reactors in service or under construction at the present time.

(*To be continued*)

In the paper on which this article is based, the authors acknowledge C. A. Parsons & Co., Ltd. for permission to make use of the detailed information.

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Using U.K.'s 'Know-How'

MORE and more scientists and technicians are coming from overseas countries to Britain for training in nuclear energy work by the United Kingdom Atomic Energy Authority, or to co-operate with Authority scientists in atomic research. Britain now has agreements to collaborate in the development of nuclear power and techniques with 15 countries and one international organization. These are the United States, Israel, Japan, India, Australia, South Africa, Denmark, Norway, Sweden, Portugal, Belgium, the Netherlands, West Germany, France, Italy and EURATOM. In addition, Britain has always maintained the closest contact with the Canadian atomic energy programme. One of the major services Britain is providing is to make available the knowledge gained by her own experience. This is done in three schools: The Reactor School, at Harwell, which has trained 1,777 students, including 450 from overseas, since it started in September, 1954; The Calder Operations School, at Calder Hall, with 312 trainees in all since January, 1957, including 115 from abroad; and The Isotope School, now at Wantage, with a total of 2,053 students of whom 747 were from abroad, trained since work began in April, 1951. Apart from training and collaboration attachments under the above agreements with Commonwealth and other countries, two major international programmes are now being implemented in the U.K.: one is the International Atomic Energy Agency's fellowship programme and the other the DRAGON Project. Under the first, the UKAEA has received or made arrangements to receive 62 Agency fellows. Under the DRAGON Project to build in concert with 11 European countries of the Organization for European Economic Co-operation a 10 MW (heat) prototype high temperature gas-cooled reactor, large numbers of expert staff have been arriving at Winfrith in Dorset since mid-September.

Accelerator Projects

THREE new types of accelerators have been developed by the High Voltage Engineering Corporation to cover industrial power requirements ranging from 10 kW to 1,000 kW. The first, an insulated core transformer accelerator, utilizes a segmented magnetic core which allows large voltage build-ups in the secondary windings of each segment without the requirement for high voltage insulation between winding and core, which is the limitation of conventional transformers. Each core segment, with associated windings and rectifier, is a compact d.c. power supply capable of delivering 30 kV and 40 milliamperes of current. Voltage addition is obtained by distributed series capacitance between core segments. The overall efficiency of power conversion is about 90 per cent. A prototype utilizing this principle has been constructed and is now under test at HVEC's Burlington plant. This type of accelerator has the potential for delivering up to a megawatt of power. The generator can also be used to accelerate intense currents of positive ions for ion-plasma fusion studies or other research. Another type of electromagnetic voltage generator developed by high voltage is the "transmission line" accelerator. It is described as an inherently simple device for obtaining over 20 milliamperes average beam current in the power range of 10 kW to 75 kW, depending on energy range. A prototype is being constructed. Power efficiency is expected to be over 80 per cent. A third type, the multiple disc accelerator is analogous to the Van de Graaff accelerator in that voltage is generated electrostatically. Its expected power range is 25 kW to 100 kW. The first model is being constructed to deliver 15 to 25 milliamperes at 1.5 MeV. Principles involved may also be used to develop machines for propulsion of space vehicles by means of ion thrust.

Take-Over by H. & W.

HILGER & WATTS have acquired the whole of the issued share capital of The Infra-Red Development Co., Ltd., Welwyn Garden City. IRD Ltd., was founded in 1946 and specializes in the analysis of gases by non-dispersive infra-red techniques, primarily for industrial purposes. From the start, the firm has been under the technical control and management of Mr. W. B. Bartley, who will remain managing director. It will continue to operate at its works and offices in Welwyn Garden City and will continue to develop and manufacture the gas analysers on which it has built its reputation.

NUCLEAR NEWS

N-Briefs

Plessey Nucleonics Ltd., of Northampton, are to supply burst slug detection equipment for the UKAEA's Advanced Gas Cooled Reactor under construction at Windscale.

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The first uranium supply transaction to be carried out by the International Atomic Energy Agency has been concluded. Under it Japan has received 3,042 kg of natural uranium for $U.S.107,991.

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Oak Ridge National Laboratory are to build in 1960, a pilot plant for the reprocessing of power reactor fuel elements. It will take about a year to build and cost about $4,750,000.

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The Birmingham office of Keith Blackman Ltd., has been moved from New Street, to 1651, Pershore Road, Birmingham, 30. Telephone number is Kings Norton 4151/2.

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Rio Tinto and Dow Chemi AG, the Swiss subsidiary of the Dow Chemical Co., have jointly acquired the share capital of Thorium Ltd., from ICI Ltd., and Howards and Sons Ltd.

Associated Electrical Industries Ltd., are to supply the CEGB with 275 kV air-blast switchgear to control the output of the Trawsfynydd nuclear power station. Value of the contract is £900,000.

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The South East London Technical College is holding a course of ten evening lectures on "Linear and Non-Linear Sevo Control Systems" starting from January 20th.

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Dounreay fast breeder reactor went critical recently. It will go through a period of low power operation for a few months, followed by a shut-down for possible modifications.

* * *

Argonne National Laboratory are to add a 10 MeV tandem Van de Graaff particle accelerator to their physics equipment. It will be supplied by the High Voltage Engineering Corporation and will cost $1m.

* * *

Sir John Cockcroft, OM, FRS, is to preside at the Radiation section of the Health Congress to be held at Torquay, April 25th to 29th, 1960. Organizers of the Congress are the Royal Society of Health.

* * *

Isotopes Developments Ltd., of Aldermaston, have just completed a tour of European countries with their mobile demonstration unit. Universities, research centres, hospitals and industrial organizations were visited.

* * *

"More Power from the Atom," "Radioisotopes in Industry," and "Metals of the Nuclear Age," three UKAEA films, won awards at the recent International Festival of Technical, Industrial and Agricultural Films, Rouen, France.

* * *

Laurence, Scott and Electromotors Ltd., would like to hear from ex-apprentices for the purpose of arranging a reunion during the 1960 Electrical Engineers Exhibition. They are asked either to write to Mr. W. F. Symes at Gothic Works, Norwich, or to telephone Mr. T. J. Barfield, Temple Bar 5223.

* * *

British Thomson-Houston Co., Ltd., Metropolitan-Vickers Electrical Co., Ltd., and Siemens Edison Swan Ltd., from January 1st, 1960, onwards will be known as Associated Electrical Industries (Rugby) Ltd., Associated Electrical Industries (Manchester) Ltd., and Associated Electrical Industries (Woolwich) Ltd., respectively.

* * *

The Hawker Siddeley Nuclear Power Co., Ltd., are to supply the UKAEA with a reactor based on their JASON, the prototype of which was recently inaugurated by Sir John Cockcroft. The UKAEA reactor, to be installed at the Winfrith Atomic Energy Establishment, will be known as NESTOR (Nestor was one of the Argonauts led by Jason in the quest for the Golden Fleece) and will cost about £50,000.

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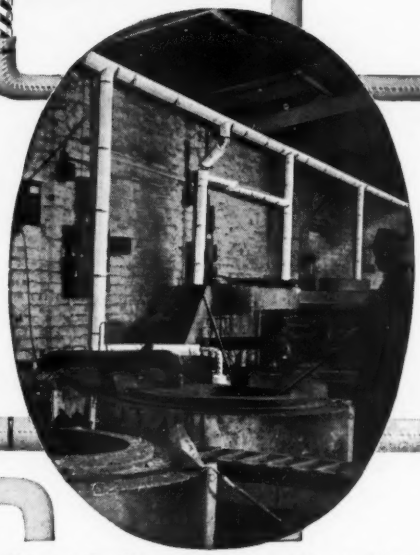

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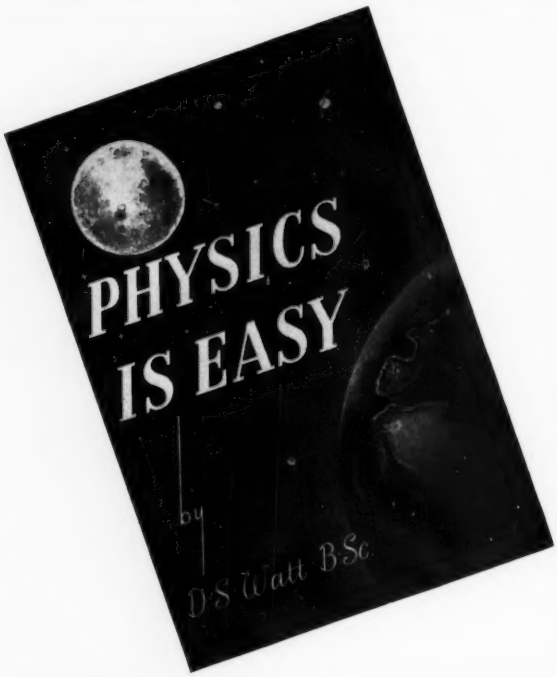

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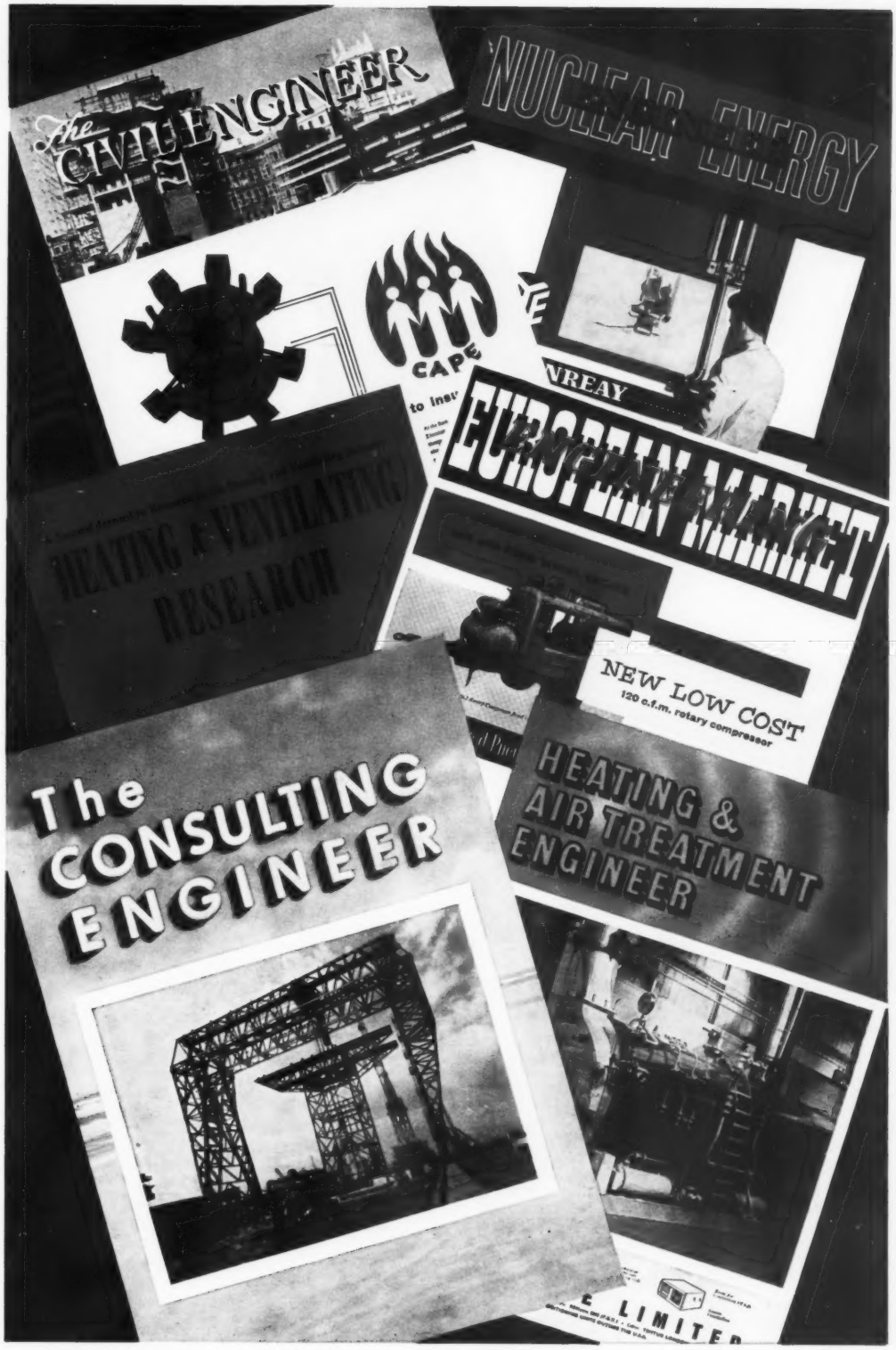

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